Opportunity Knocks at

ENERGO'83

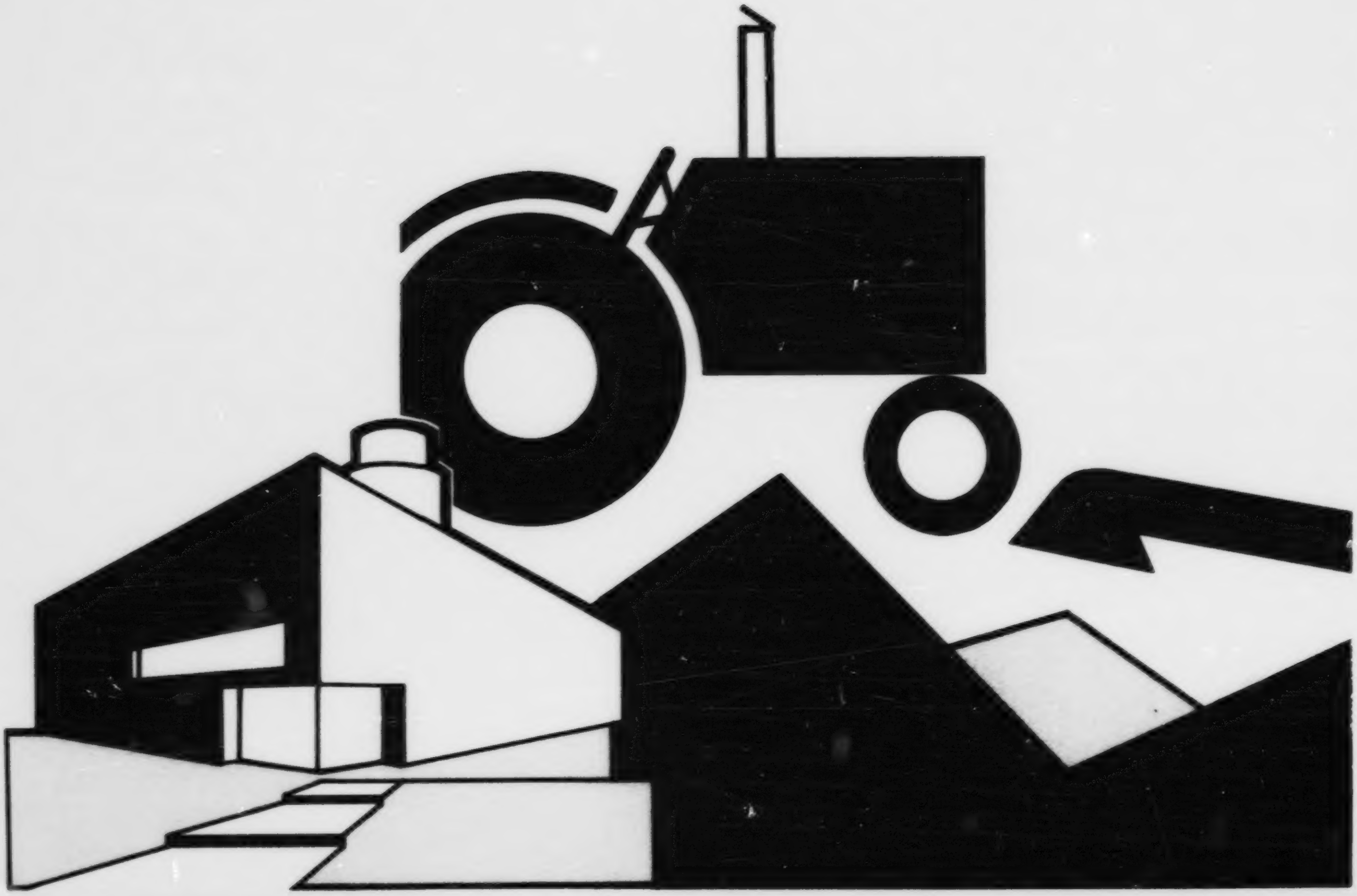
Ontario Energy Opportunities in Biomass

March 6-9, 1983, Toronto, Ontario

Conference Papers

Ministry
of
Energy
Ontario

Honourable
Robert Welch, Q.C.
Minister



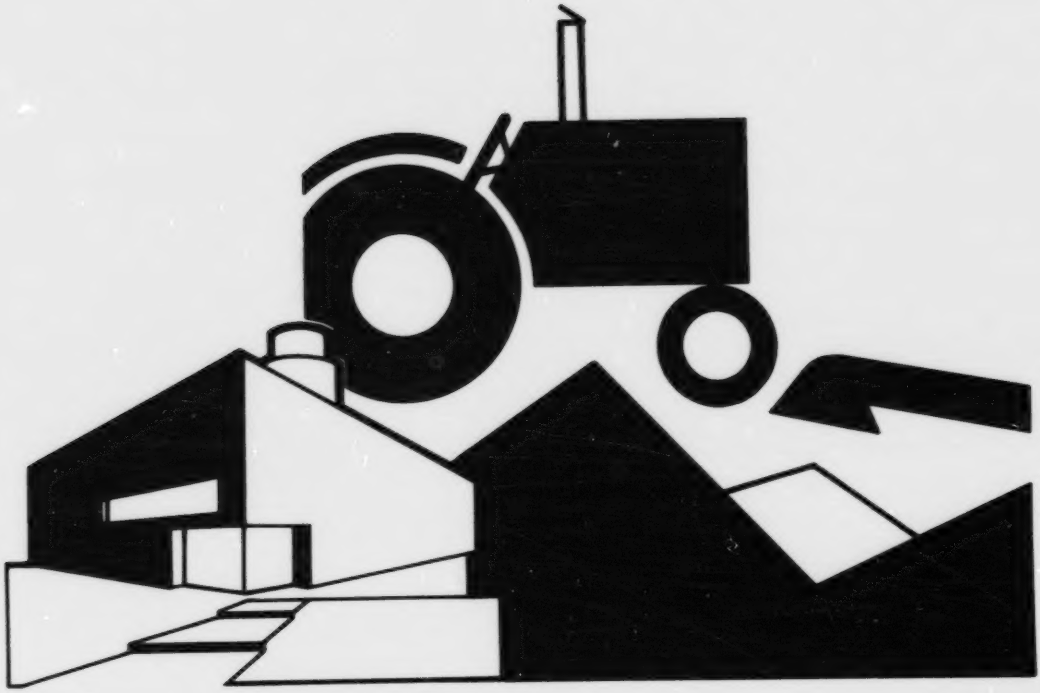
Opportunity Knocks at

ENERGO'83

Ontario Energy Opportunities in Biomass

March 6-9, 1983, Toronto, Ontario

Conference Papers



Conference Organization

Executive Committee:

Glenn R. Thompson
Roger M. R. Higgin
Michael Van Dusen

Planning Committee:

Richard J. Fry
Calista A. Thompson
Nancy P. Marshall
Debi Smithson

Technical Committee:

G. Carman Chisamore
Neal R. Ahlberg
Paul Bakker
Ronald P. Alton
Kenneth J. Thomson
Donald W. Gallagher

Conference Planners:

Convention Consultants of Canada Ltd.

Trade Show Planner:

Showkraft Canada

Foreword

The theme of ENERGO '83 is Ontario Energy ***Opportunities*** in Biomass – opportunities for private citizens, manufacturers, industry and municipalities to produce and use economic, safe and convenient forms of energy, derived from Ontario's indigenous and renewable resources.

Interest in developing renewable resources, including energy from waste and biomass, solar energy and alternative fuels, began in the 1970s. Since then, this interest has fluctuated with the availability and price of oil.

Currently, oil prices have dropped, and consequently, the perceived urgency for new and renewable resources has diminished; but only temporarily.

The International Energy Agency has warned oil importing nations about a false sense of security from a relatively stable world oil situation. We agree, and believe these soft oil prices merely indicate a lull that we must use to our advantage. By developing our new and renewable energy technology now, we can increase our security and readiness for any future series of oil price shocks.

Ontario's program in Energy from Waste and Biomass is three years old. We have investigated the promising energy from waste areas, and have made some important choices. Now we are ready to put our experience into practice.

This international conference signifies our commitment to encourage the installation and operation of energy from waste and biomass projects throughout the province. It is a milestone in Ontario's energy development.

I welcome your participation in ENERGO '83, and sincerely expect that we will work together in further advancing our opportunities in this important area.

Glenn R. Thompson
Deputy Minister
Ministry of Energy
Province of Ontario

Contents

Municipal Solid Waste

Review of Technology of EFW Plants
J. Mulholland 1

Incinerator Emission Control Technology – Present and Future Processes
Alois Scharsach 8

Use of Refuse Derived Fuel as a Supplementary Fuel in Cement Kilns
A. F. Robb and R. Luka 18

The Use of RDF as a Burnout Fuel in Brickmaking
Howard Penn and E. E. Barry 32

Ames Solid Waste to Energy System 1975 – 1982
Arnold O. Chantland 44

Recovery and Utilization of Landfill Gas
Anthony J. Crutcher and Walter Graziani 57

Operating Experience at the St. John's University – Energy from Waste Project
Father G. Tavis 65

Semi-Suspension Burning Operating Experience at Hamilton and Akron
Joseph W. Kennedy 73

Operating Experience at Quebec Metro Incinerator
Hervé Aubin and Michel Roux 81

District Heating Project Implementation: "A Developer's View"
Thomas R. Casten 91

Private Sector Involvement in EFW Projects
D. Volter 96

The Financing and Risk Sharing of Energy from Waste Facilities in Ontario
D. R. Craw 101

Forest

Use of Wood for Energy in Ontario – Implications to Forest Management
E. Markus 105

Energy from Wood in the Pulp and Paper Industry
H. D. Paavila 111

Residential Wood Heating Equipment
N. Fleisler 115

Forest Energy Biomass Harvesting Technology
Review of Selected Approaches
Denis Brière 118

Hybrid Poplar Energy Plantations in Ontario
H. W. Anderson and L. Zsuffa 134

Pellet Fuel From Wastes
A. S. Borowski 146

The Utilization of Biomass Residuals at the Great Lakes Forest
Products Thunder Bay Complex
A. J. Bruley 152

Woodfired Heating Facility at Grenville Christian College
John P. Childs and Daniel E. Ortolani 158

Contents

Residential Central Heating Systems Using Forest Wastes 164
R. J. Brandon

Efficiency of Wood-Burning Appliances 172
E. A. Fernbach

Agriculture

Energy Considerations in Crop Production 176
T. B. Daynard

Energy Considerations in Livestock Production 180
W. D. Morrison

Energy Considerations in Greenhouse Production 185
Ir. W. P. Mulder

Biomass – A Crop Scientist's View 188
N. C. Stoskopf

Matching Engines with Fuels Developed from Agricultural Materials 194
K. L. Walker

Energy Production by Anaerobic Digestion of Livestock Wastes 199
H. D. Monteith, R. J. Rush and A. R. Stickney

Disclaimer

These conference papers, prepared for the Ministry of Energy for Ontario, are published as a public service for the information of the public. The Ministry does not, however, warrant the accuracy of its contents and cannot guarantee or assume any liability for the effectiveness or economic benefits of the devices and processes described in the papers.

Municipal Solid Waste

Review of Technology of EFW Plants

by:
J. Mulholland
The Proctor & Redfern Group

The underlying theme of this conference is energy – Energy From Waste in particular for this session. Historically, man's waste has been disposed of by burial or burning beginning with the very simple restraints of early history "dispose of it out of sight or down wind" to the severe restraints on limiting environmental impact existing today that are in keeping with controlling the hazards associated with waste. Historically, there has been little incentive to utilize waste at the same time as disposing of it. The recognition of finite quantities of quality available fuels and the redefined socio-economic value of these fuels resulted in a rekindled interest in energy from waste in North America.

The recovery of energy from waste began in North America at the turn of the century in New York City and in Europe in Hamburg, Germany. Numerous plants were constructed up to World War II, that both incinerated waste and recovered energy. The destructive impact of World War II on waste disposal systems in Europe required the Europeans to rebuild their systems and thus gave them a chance to advance the technology from its pre-war state. This they did resulting in the development of the modern mass burning incinerator plants that are now being looked upon with favour in North America, 20 years after the fact.

These facilities went through a horrendous development period where many plants constructed, and others under construction were faced with major operating problems that showed up in the very first plants built, especially the water wall incinerator concept. Perseverance, money and a lot of technical effort was expended by European designers and their clients to overcome these difficulties resulting in design criteria which today allows them to design a high quality, reliable, efficient energy from waste facility utilizing mass burning technology. There is no doubt this technology is presently the most reliable available for energy from waste facilities.

Although mass burning technology and most corporations involved in the design, manufacture and sale of these systems world-wide are well known, their products do not constitute a panacea solution for energy from waste. They constitute one viable system available. Other methods and systems have been tried, some successful and some unsuccessful.

Energy from waste technology reviews often consist of a review of various types of systems and equipment presented in a general format to introduce a technical session such as "Energo '83". It is our intention to depart somewhat from this typical format, which would only repeat many things you have already heard elsewhere, and place our emphasis on more general fundamental "technical" items that must be overcome to achieve a viable energy from waste system. Later authors will present specific case histories or equipment available which they feel meets the public's social and economic needs with respect to municipal solid waste disposal.

We began our comments with reference to the "historical" method of disposal of garbage which in today's euphemisms we call "municipal solid waste" or "energy from waste". Today's euphemisms must not cloud the real problem – it is garbage we have to dispose of, not energy we have to recover. There is a difference between "energy in waste" and "energy from waste".

The historical means of disposal remain the only two available. Either we bury it or we burn it. Any other process ultimately winds up with these two end results. It is from here we begin our technology review.

Energy – The Burial Disposal Option

Waste that is buried is commonly thought to be unavailable for recovery of energy, but in reality there is a long-term availability of energy through the anaerobic decomposition of the waste producing methane gas. The energy available is in the form of a medium heating value methane rich gas very similar in composition to the digester gas obtained through the anaerobic digestion of sewage sludges – an available source of energy in sewage treatment plants for many decades. The indicated properties of the gas from a landfill site may be represented as shown in Figure 1. This figure also indicates how the various stages of theoretical decomposition of organic matter affects gas composition.

The available methane generation from the anaerobic decomposition of organic matter may be depicted as shown in Figure 2. This figure illustrates the general decay process as it is presently understood. The total available energy in this form is a small percentage of the total energy content of the original waste due to energy lost in (1) the anaerobic process, (2) the lateral and vertical gas losses out of the landfill site, and (3) the recovery potential of the remaining gas quantity. The recovery problem is similar to that faced in recovering oil from an oil field. This does not preclude its viable use as an available energy source as evidenced by several attempts to recover this energy at different landfill sites, most notably in the U.S.A.

Although the energy available for recovery is low, it is in a form that is properly defined as a fuel, i.e., a gaseous mixture with good combustion characteristics. Compared to other methods of recovering energy from waste this is a relatively inexpensive means of obtaining fuel, but one that is very restricted (1) by time as to its earliest availability, (2) the time period over which it can be utilized, and (3) the rate at which it can be utilized.

A later paper in this session will address this energy from waste option in a more specific manner.

Energy – The Burning Disposal Option

The burning disposal option includes the various thermal destruction technologies that have been attempted including pyrolysis, gasification, starved air combustion, mass burning, etc.

As mentioned in our opening remarks, the most successful burning disposal option has been the European developed mass burning technology which today is gaining acceptance in North America some 20 years after the fact. The delay has been one of government intervention projecting the image of incineration as environmentally less acceptable than other alternatives. Fortunately, the pendulum is returning to a more balanced assessment and commentary on these technologies.

The burning disposal option has a number of available alternatives which show reasonable promise from a technical point of view. These may be grouped as:

1 Mass Burning Incinerators

2 Starved Air and other Modular Incinerators

3 Refuse Derived Fuel (RDF and dRDF)

4 Co-disposal

Notably absent from the list is "pyrolysis" which systems have proven to be unacceptable as a waste disposal option due to the large number of technical parameters which have yet to be properly resolved. This was a case of going too big too soon. The fundamental law of "time money – perseverance", the backbone of any successfully developed technical system, was violated.

Time – too short a time frame was allowed for proper development.

Money – the true cost for the time frame allowed was too great.

Perseverance – jumping from small pilot scale systems of 5-50 t/d to 200 t/d and larger did not allow the resulting problems to be properly addressed.

Mass Burning Incinerators

This technology, in simple terms, involves the pre-sorting of waste in a waste pit using a crane operated grab with which the incinerator is charged through a charging throat; the waste charge passes into the furnace section where it is transported on a moving grate system that both gently transports the waste and tumbles it to properly expose the waste to air admitted under the grate; combustion of fixed carbon and volatization of the volatile matter in the waste takes place; the resulting products of pyrolysis and gasification mix with admitted air above the pile to complete combustion in the freeboard area of the furnace.

Starved Air Incinerators

Starved Air Incinerators (also known as controlled air or modular incinerators) may be considered as the present generation of, though not directly born out of, the small special application incinerators for waste that served hospitals, and apartment buildings. The need to process municipal solid waste involving more than typical household garbage was married to the "starved air" combustion concept wherein the combustion process is broken into two relatively distinct steps: (1) pyrolysis and gasification, (2) gaseous combustion.

Starved air incinerators might be thought of as small mass burning incinerators broken into two chambers. The first (or primary chamber) contains the moving grate and waste pile, while the second (secondary chamber or afterburner chamber) is fed with sufficient combustion air to permit the hot gases from the primary chamber to ignite and combust. It is an attempt to effect a distinct separation of the combustion process to minimize some of the problems associated with direct combustion. Though these units have effected a reduced particulate carry-over from the combustion process, they have not necessarily improved on all the problems in incinerating waste. Some compromise is required in any system design in order for it to properly function. The starved air incinerator requires a more careful charging than that required for a typical mass burner. There is also the "burnout" of combustibles where the mass burning incinerator seems to be capable of a consistently higher burnout. Fixed carbon in the waste amounts to 15% ± of the combustibles of which half remains in the ash after combustion in a starved air incinerator of present day design. The mass burner achieves close to 90% ± burnout of the fixed carbon.

The starved air incinerator has a reduced primary furnace volume in accordance with the reduced volumetric requirements related to the burning of the fixed carbon, the gasification of the volatile matter, and the pyrolysis (or cracking) of some of the fixed carbon with the water vapour driven off in the drying of the wet waste. The resulting gas is a low heating value gas relatively free of particulate matter which is ignited in the secondary chamber with an appropriate quantity of excess air to complete combustion. The minimum particulate carryover, through the reduced turbulence occurring in the primary chamber, significantly reduces the pollution control equipment that may be required for the final air emissions.

The status of these systems to date is such that they, for the most part, meet the objective of reducing particulate emissions. However, the emission level standards imposed by some authorities require that these systems be fitted with air emission control equipment in order to meet their standards.

The small size of these units has resulted in a preference for this particular technology in the 50-200 tpd plant size range. Drawbacks in their operation are (1) reduced overall efficiency when compared to the mass burning technology, and, (2) low fixed carbon burnout. In favour of the starved air incinerator is its small "modular" size which can be factory pre-fabricated and its lower initial capital cost, when compared to the mass burning technology systems in the smaller plant size range.

Refuse Derived Fuel (RDF)

In speaking of refuse derived fuels one should at first define what a fuel is before attaching such a term to municipal solid waste. Fuels may be depicted as shown in Figure 3 where we progress from the "perfect" fuel (hydrogen gas) to the "worst" pseudo fuel (municipal solid waste). In the sense of perfection, hydrogen gas burned with pure oxygen is the only nonpolluting fuel available. To get it without imperfection is its problem.

Natural gas, liquified petroleum gases (LPG), light and heavy oils, wood and coal have all been well developed for use as fuels, both as to preparation for use as a fuel and the equipment to effectively combust it achieving maximum energy recovery. Among the pseudo fuels, peat and wood waste are in the forefront of the development process to achieve quality combustion systems. They are in a very advanced development and commercial state. Sewage and other sludges likewise have been through much of the developmental process so that they are now able to be prepared for use as a fuel through the removal of their water content suitable for specially designed combustion systems. Municipal solid waste, on the other hand, is still in the development phase of finding suitable means to properly prepare it as a fuel.

Municipal solid waste, unlike the other pseudo fuels, has a rapidly varying composition not only as to moisture content, but as to inert materials and the quantity and type of combustible materials in the waste, and numerous other factors. At one moment you have a crowbar and at the next plastic film quite different properties to be addressed when you do not know when either will appear in your waste stream.

Attempts were made to adapt mining technology, used in preparing ore concentrates or other metallurgical processes, to the preparation of municipal solid wastes into a processed fuel. Those involved in that early work are aware of the many problems faced and the successes achieved. It cannot be too lightly emphasized that the variable non-homogeneous detrimental nature of municipal solid waste makes it an adversary worthy of all due respect.

The simplest refuse derived fuel is obtained through the pre-sorting of the waste stream, excluding the heavier industrial component, so that it is a reasonable "domestic" type waste amenable to shredding. The material can be shredded after separation of metallics, etc.; and fed directly to a semisuspension type combustion system. The early attempts at this particular form of preparing a fuel showed promise. Further work has resulted in the semi-suspension burning of municipal waste being another technically viable alternative. Economic viability must still be proven.

The extent of the attempts to prepare municipal solid waste into a fuel can best be illustrated by two examples: densified RDF and Eco Fuel II. Densified RDF has only one cause for existence – to be transportable. Unfortunately, the cost to make it transportable generally exceeds its value as energy. In addition to the processing plant there is the requirement for transportation, receiver's storage and material handling facilities. The processing is a marvel of technology, but is it realistic?

Likewise, Eco Fuel II has not returned its financial promise. Again, it is a technical marvel that prepares this fuel, but the operating parameters and the financial costs are beyond reasonableness.

Lest we forget – There is a difference between "energy in waste" and "energy from waste".

Co-Disposal Options

There has been a great deal of emphasis in recent years on the co-disposal of municipal solid waste with sewage sludge from municipal treatment plants. These co-disposal options have ranged from composting to thermal drying of sewage sludges and their reintroduction into the municipal solid waste combustion unit. Like the several systems developed for the disposal of municipal solid waste there are several processes and systems available world-wide for the preparation of sewage sludge for co-disposal option. Again, the Europeans and the Japanese have been recent leaders in this field with a number of plants capable of producing such product in operation. They have successfully, but not without operational difficulties, co-disposed of sewage sludge with municipal solid waste.

The best of these systems have been the convection type dryers, either the rotary type or the cagemill concept producing pellets or dust suitable for reintroduction into designed for the purpose burners on municipal solid waste combustion units. Attempts with conduction type dryers are much less proven and should be considered as still in the developmental phase as far as proving their long-term operational characteristics, maintenance requirements and replacement life.

Systems available range from those with several thousand operating hours of experience to as little as a few hundred hours in the sense of others on test units or their first installation. Technically there is no great problem to be faced in the thermal drying of sludges and co-disposing of it other than recognizing again that it is a difficult waste stream to work with. The theoretical concepts are available, it is the practical equipment and its proper application and operation that must be looked at and appreciated before you can have a successful system capable of being integrated with an energy from waste facility serving a municipal solid waste stream.

Technology Review and The Engineer

No technology review is truly complete without referring to the reviewer – the engineers. I would make personal comment here that the engineering profession has placed upon its shoulders a grave responsibility to properly assess the true risk involved in the technical aspects of any energy from waste system. It is one thing to produce volumes of reports full of figures, tables, double and triple spaced lines, many pages – that can be done by anyone. The true engineering professional work is to see that the final reports each have substance and stand above reproach in any technical review or environmental hearing wherein they are placed for justification of a facility.

Unfortunately, not all projects have included a full appreciation of the risks that are faced by the ultimate owners and operators and financiers (the tax payers) who have to live with it for many years in the future. To some, it is a nice thing to say than an energy from waste facility will save you money. To my ears it is not sweet music to hear that an energy from waste project is going to make a community money. The myth has been dispelled time and time again to the sad suffering of the innocent. There is a vast difference between saying that energy from waste can save you money and that energy from waste will make you money.

We, the engineering profession, have as our duty to the public to ensure that these facilities have their true technical risk outlined clearly and concisely so that an appropriate dollar value can be assigned to the risk covering the unkowns that exist in a municipal waste system – especially an energy from waste facility. With this clearly presented it is possible to properly assess the "viability" of the project on a reasonable and rational basis. The public hearing process can then concentrate on the real issues of an energy from waste proposal; i.e, the socio-economic aspects of the proposal.

Energy from waste facilities generally provide a good rate of return on the incremental investment for the energy recovery portion of the facility but they do not provide a positive rate of return on an overall facility except under some very unusual circumstance which may be questionable in the long term.

The professional engineer must ensure a thorough evaluation of the technical aspects is made including: (1) availability of the system for operation, (2) variance in availability of waste and its nature, (3) waste and end user load profile variance day-by-day, month-by-month and year-by-year, and (4) percentage of energy that can reasonably be expected to sell to the end user. It is necessary to include proper assessment as to the system and component operating life and need for replacement. Maintenance must be addressed as a technical problem with appropriate time factors so that maintenance costs and downtime loss of energy sales may be properly included.

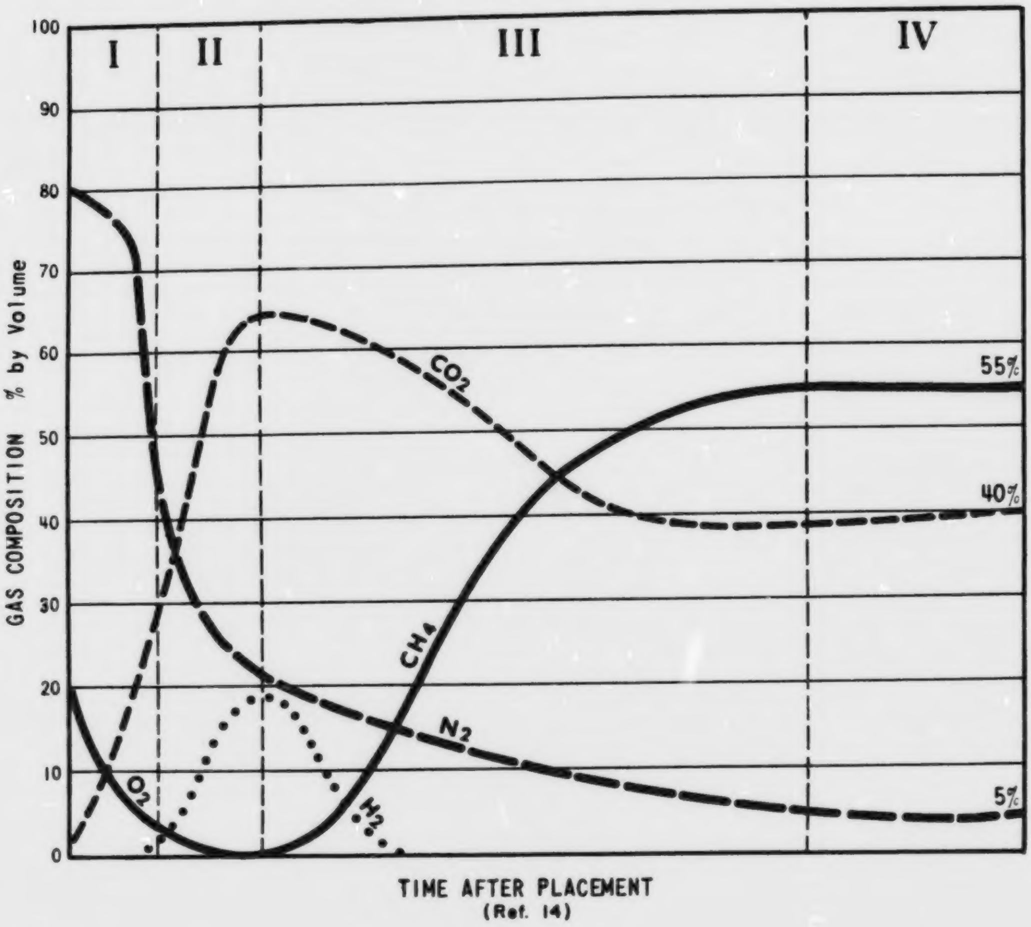
There is the subject of beautiful sales literature. There are the claims of equipment used in one industry than can be transferred over to municipal waste disposal systems. There is equipment that has not fulfilled sufficient operating hours, (and we don't mean days or weeks, we mean years) for a proper evaluation to be made. An energy from waste facility, like any boiler plant, is meant to have a useful life of not less than twenty years and preferably thirty years or even forty. The real risks (technically) must be identified with clarity so that the public understands them and so that the approval process may address them to the benefit of all concerned.

In Closing

There are municipalities and/or private enterprise willing to take substantial increased risk incorporating newer technologies and equipment that does not have long-term operating data because they recognize that it is a duty of individual communities and companies to accept responsibility to permit furthering of the state-of-the art. They are prepared to do this cognizant of the risk they take. They ask that senior levels of government likewise accept a sharing of their risk and stand with them in such endeavors. All must be prepared for those consequences that follow unsuccessful endeavors and approach the resulting problem in a manner to resolve it conducive to everyone's well being. We would not be in the favourable position we are today if communities had not taken risk along with industry and other levels of government who had the financial or technical resources to further the state-of-the-art.

We must recognize the true nature of the problems we face in disposal of waste and accept that the energy available within that waste can, is, and will be recovered where warranted. Energy from waste is an idea, a dream, in North America that should have become a greater reality two decades ago, but factors in North America were not conducive to its being implemented. Our advantage now is that many others have been down numerous paths before us, and we can benefit from their experience to further the state-of-the-art. Energy from waste facilities can relieve the demand for hard pressed, high quality energy fuels allowing their use for more appropriate purposes by society.

Evolution of Typical Landfill Gas Composition. figure 1



I. Aerobic

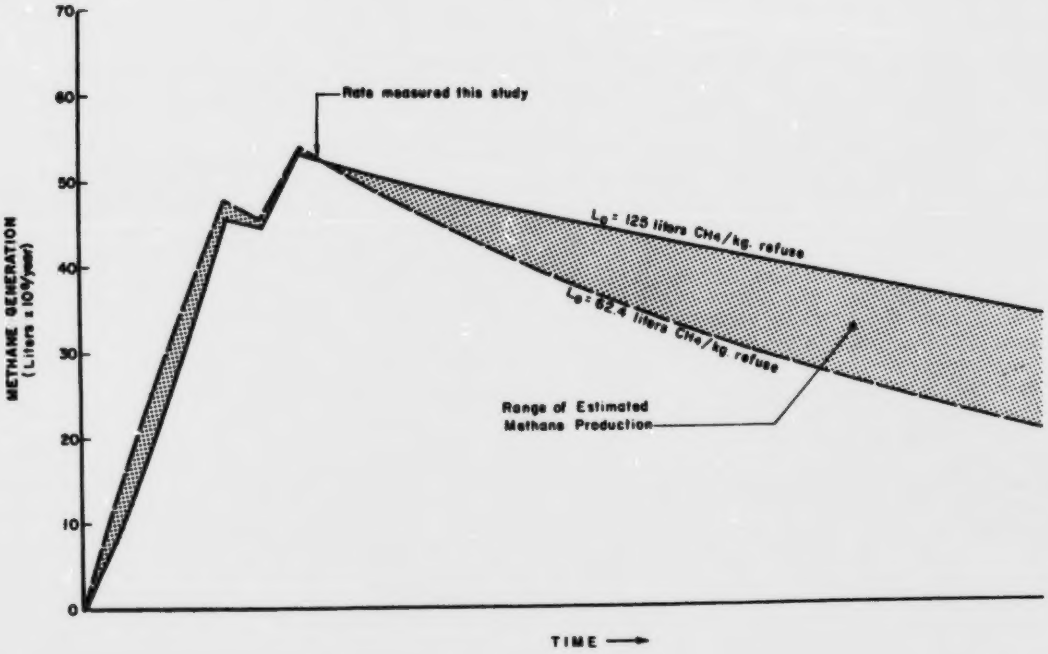
II. Anaerobic, Non-Methanogenic

III. Anaerobic, Methanogenic, Unsteady

IV. Anaerobic, Methanogenic, Steady

Estimated Methane Production (Scholl Canyon Kinetic Model).

figure 2



Incinerator Emission Control Technology – Present and Future Processes

by:
Alois Scharsach
Von Roll Ltd.
Environmental Engineering Division
Zurich (Switzerland)

Abstract

Waste is no ideal material for incineration, because its composition varies in a wide range over the seasons and even within a single week. The emission of hazardous substances with the flue gases such as fly-ash, HCl, SO_2, HF and NO_x is highly dependent on this composition.

In Europe, a very effective elimination of the fly-ash by electrostatic precipitation has been the state of engineering for many years.

In contrast to this, the first plants for the reduction of the gaseous pollutants are realized only since 1975. The different processes for the reduction of gaseous pollutants, especially wet scrubber systems and dry scrubber systems are described. The cleaning efficiency and the specific costs of some processes are discussed.

Theoretical Background

Refuse and waste are produced everywhere and every day, in private households and in industry.

The problem is to get rid of all this refuse and waste with as little contamination of the environment as possible.

The main choices for disposing of refuse and waste are:

- recycling
- landfill or ocean dumping
- composting and
- thermal decomposition by combustion.

In urban areas, combustion is the method that will ultimately succeed.

This paper handles only the disposal by incineration and the emission problems connected therewith.

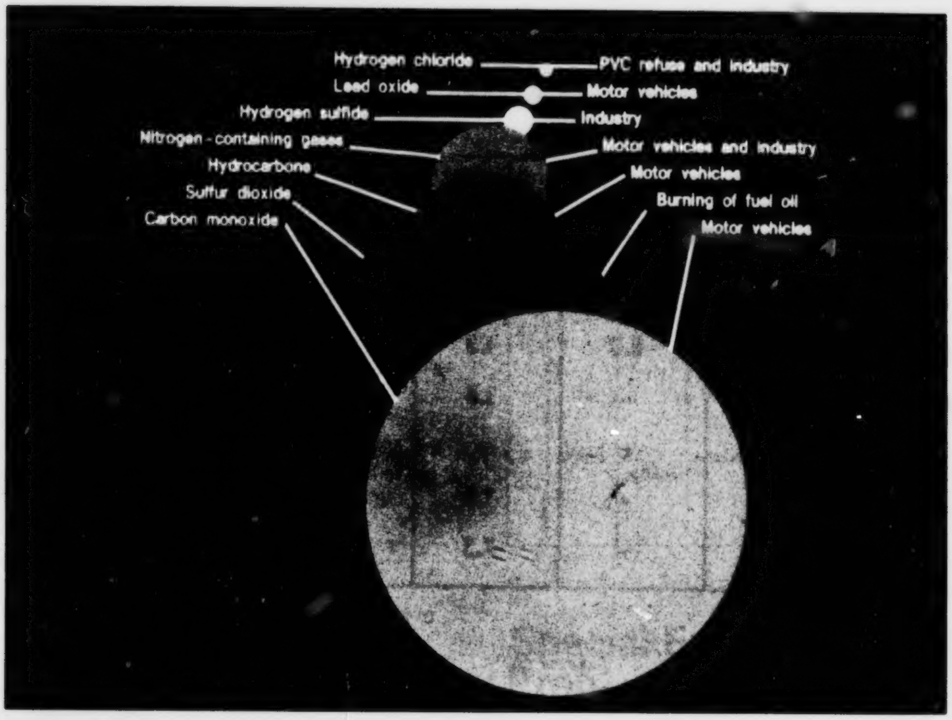
Waste Combustion

The first figure shows a comparison between the amounts of various types of atmospheric pollution in Sweden caused by combustion gases.

We have good reason to assume that the situation in other Western countries is similar.

Comparison Between Amounts of Various Types of Atmospheric Pollution in Sweden

figure 1



The picture shows clearly that the relatively low emission of hydrochloric acid is not the big problem. Nitrogen-containing gases and, above all, sulphur dioxide are generated by combustion reactions to a much larger extent.

Hydrocarbons and carbon monoxide are formed in large amounts too. But these compounds can be degraded biologically to a large extent. Hydrochloric acid, nitrogen-containing gases and sulphur dioxide, however, cannot be decomposed by biological means. As soon as these compounds enter into the atmosphere they escape any human influence, but sometime and somewhere they return to the surface mostly in the form of acidic rain.

The acidic precipitation causes much trouble to the chemists engaged in environmental problems. The Las Vegas Symposium of the American Chemical Society 1982 was entirely devoted to the subject of acid precipitation.[1]

The only possibility to get the knack of this problem is an efficient reduction of the emission of these noxious gases. This is possible by means of chemical reactions. The exhaust gases of any combustion plant must be treated by a washing process to eliminate most of the noxious gases, to prevent their emission into the atmosphere.

Much research has been done, and many papers have been presented on combustion processes, particularly on domestic refuse. For technical purposes, an overall formula is exact enough.

$C + H + S + N + Cl + O +$ air-oxygen
will convert to $CO_2 + H_2O + SO_2 + NO_x + HCl$

(stoichiometrically not exact)

But, as the composition of domestic refuse varies, it is not possible to give exact stoichiometric equations for its combustion.

Ultimate Analysis of Some Fuels and Domestic Refuse

figure 2

	fuel oil light	fuel oil heavy	coal Pittsburg	coal Ruhr	brown coal center Germany	domestic refuse
carbon	86.0	81.7	76.2	74.1	28.6	22.9
hydrogen	14.0	13.1	5.0	4.6	2.2	2.8
oxygen	-	-	7.1	9.4	10.8	15.1
sulphur	-	5.0	1.3	0.9	3.0	0.4
nitrogen	-	-	1.5	0.4	0.4	0.3
chlorine	-	-	-	0.1	-	0.3
water	-	-	1.5	6.2	48.0	26.6
ash	-	-	7.3	4.3	7	31.6

It must be said clear and explicit: Very little is known yet about the chemical reactions occurring during the combustion of domestic refuse. To verify this drastic statement the combustion of the most simple hydrocarbon, methane may be mentioned. The overall formula of this process is very simple:

$CH_4 + 3\ O_2 = CO_2 + 2\ H_2O$.

In actuality this so-called simple reaction is extremely complicated:

1 elementary reaction as per overall formula, however

1972 44 elementary reactions were known[2]

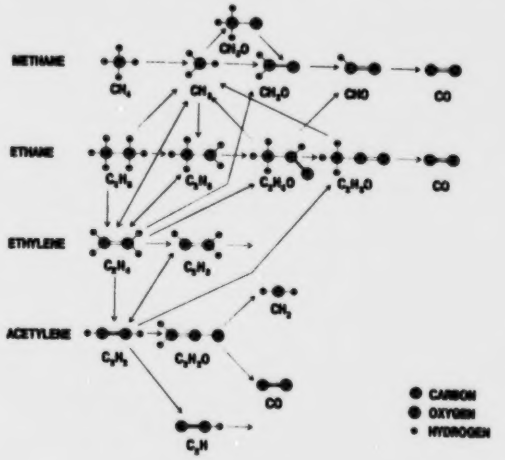
1979 80 elementary reactions were known[3]

1981 More than 100 elementary reactions were known.[4]

The chemical reactions occurring during the combustion of simple hydrocarbons are so complex that they can only be described by flow diagrams.[5]

Flow Diagram of Combustion

figure 3

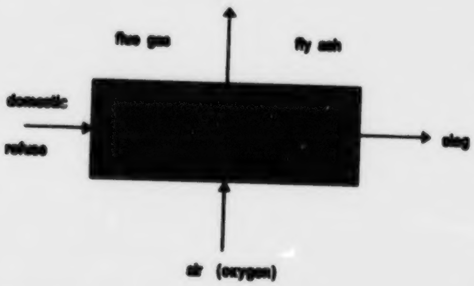


Without further discussion of this example it is possible to say that during the combustion of the very complex "fuel" domestic refuse, many thousands of reactions occur successively and simultaneously. In addition to these chemical reactions there is quite a number of purely physical procedures such as evaporation.

Considering all these facts, it is appropriate to represent the combustion process of domestic refuse as a "Black Box".

Combustion of Domestic Refuse Represented by a "Black Box"

figure 4



Schematically, the process in the "Black Box" can be represented as a gradual procedure

Schematically, the processes in the "Black Box" can be represented as a gradual procedure.

Combustion of Domestic Refuse (Gradual Procedure)

figure 5

step	temperature range °C	procedure		process	
		on the grid	in the comb. chamber	chemical	physical
I	200°	drying of the refuse			-evaporation of water
II	700°	degasification	combustion	-random decomposition of large molecules -syntheses of new compounds -oxidation of small molecules	-evaporation of mercury and lead
III	950°	final gasification	combustion	-cracking of all organ. molecules -oxidation of small molecules	-evaporation of cadmium and zinc

Special Emission Problems

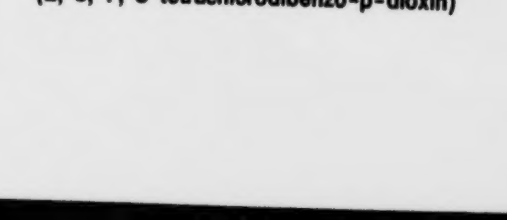
Dioxin

1978 Buser and Bosshardt[6] shocked the experts by announcing that they had discovered Dioxin (2,3,7,8 tetrachlorodibenzo-p-dioxin) in the flyash of refuse-to-energy plants.

Since the accident in a chemical plant in Seveso, Italy, Dioxin has been known as an extremely toxic organic compound.

Formula of Dioxin

figure 6



(2, 3, 7, 8 tetrachlorodibenzo-p-dioxin)

In a report of the Dow Chemical Company[7] of the same year, the collaborators of "The Chlorinated Dioxin Task Force" informed that "chlorinated dibenzo-p-dioxins are the result of commonplace burning such as fireplaces, charcoal broilers and cigarettes" and that "chlorinated dibenzo-p-dioxins may be ubiquitous in all combustion processes".

In Western Germany the emission of dioxin has been tested in 10 refuse-to-energy plants. In the LIS-Bericht No. 17,[8] it is reported that only in one plant a small emission of dioxin was detected.

In Switzerland the emission of dioxin in the flue gas of a refuse-to-energy plant has been measured at 4.0 ng/Nm³.[9] Of this value the toxic 2,3,7,8-tetrachlorodibenzo-p-dioxin constitutes not more than 4%.

The conclusion of these reports is that with lower combustion temperatures (about 550 to 650°C) the formation of dioxins is possible.

In a normally operated refuse-to-energy plant the temperature in the combustion chamber is 900 to 950°C for about 1 second. At these conditions dioxins are decomposed nearly entirely.

Global Emissions from Natural Sources and from Anthropogenic Processes (Estimates)

figure 7

emitted chemical	A natural sources 10^6 t/a	B anthropogenic processes 10^6 t/a	share of the anthropogenic emission of the total emission B as % from A+B
carbon dioxide (CO_2)	600.000	22.000	3.5
carbon monoxide (CO)	3.800	550	13
hydrocarbons (C_nH_m)	2.600	90	3
aerosols	3.700	246	6
nitrogen containing gases ($NO + NO_2$) calculated as NO_2	770	53	6.5
di-nitrogen monoxide (N_2O)	145	4	3
ammonia NH_3	1.200	7	0.6
sulphur compounds (SO_2, SO_3, SO_4, H_2S) calculated as SO_4	400	150	27

SO_2 Emission

With the combustion of nearly all fuels, sulphur dioxide is formed. From the point of view of the environmental protection, this SO_2 emission is one of the biggest problems.

According to the OECD, the worldwide SO_2 emission was:

in the year	1950 approx.	12×10^6 t
	1972 approx.	25×10^6 t
	1981 approx.	150×10^6 t

The share of the refuse-to-energy plants in this enormous amount of SO_2 emission is very small and does not exceed 1%.

But the share of the man-caused emission of SO_2 in comparison with the total global SO_2 emission is very high.

NO_x Emission

The formation of nitrogen oxides is coupled to numerous other reactions that occur simultaneously.

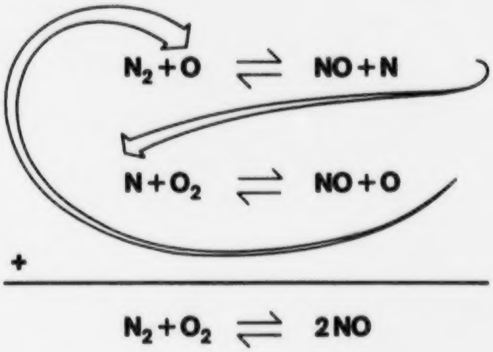
Three different ways for the formation of nitric oxide by combustion reactions must be distinguished:

- The "thermal" formation of molecular nitrogen and oxygen at high temperature in the flue gas within and behind the proper flame
- The "prompt NO" formation from molecular nitrogen and oxygen in the main combustion zone of the hydrocarbon flame
- The formation of nitrogen oxides from nitrogen chemically bound in the fuel.

Only for the thermal formation, the kinetics of the reaction are known as ZELDOVIC-mechanism.

Chain Mechanism for the Fixation of Nitric Oxide (Zeldovic)

figure 8


$N_2 + O \rightleftharpoons NO + N$
$N + O_2 \rightleftharpoons NO + O$
+
$N_2 + O_2 \rightleftharpoons 2NO$

Theoretically, the formation of NO takes place only at temperatures above 1500°C. However, due to the presence of an unknown and also continuously changing quantity and kind of catalysts in the flue gas, the formation of NO may start however, at temperatures around 1000°C.

The formation of "prompt" NO and the NO_x-formation from nitrogen chemically bound in the fuel are not yet quite clear.

For the decrease of the NO_x emission the reduction via ammonia injection has received increasing attention. Ammonia reduces nitric oxide chemically in the presence of oxygen to nitrogen in a series of gas phase reactions.

Once the NO_x is formed, there exist several wet and dry processes for the reduction of the NO_x emission.

According to the papers of the Las Vegas Symposium there is little doubt today that reactions of SO_2 and NO_x in the atmosphere result in the formation of strong acids.

But even if we will never be able to establish an absolutely proven and actual relationship between man-caused emissions of SO_2 and NO_x and acid precipitation, it is absolutely necessary to reduce these man-caused emissions of SO_2 and NO_x.

From the technical side this reduction of the emission of SO_2 and NO_x is possible. So we must do it – and we must do it now.

Emission Control Standards

The composition of the flue gases from waste incineration plants varies considerably. The content of noxious compounds in the raw gas depends primarily on the composition of the wastes burned and only in the second place on the incineration system.

In municipal waste incineration plants the content of pollutants in the untreated flue gas may be estimated as follows:

dust	5 000 – 10 000 mg/Nm³
HCl	500 – 2 000 mg/Nm³
HF	5 – 15 mg/Nm³
SO_2	200 – 2 000 mg/Nm³

The total emission of all existing waste incineration plants, however, reaches hardly 1% of the worldwide emissions caused by human activities. So it is understandable that in the well industrialized countries, the first emission control laws concentrated on foundries and other big emitters and that in the field of emission control for waste incineration plants rather little has been done.

The formation of gaseous noxious compounds such as hydrochloric acid and sulphur dioxide by the incineration of wastes was known long ago. Relatively little was known about the emission of heavy metals. The correct proof of the existence of heavy metals in the flue gases of waste incineration plants became possible only by the

Emission Limits in Several Countries

Table 1

	Heavy Metals								
	Class 1 Cd, Cr, Hg, Pb Total	Class 2 Ba, Sb, Zn Total	Class 3 Ca, Cu Total	Class 4 Fe, Sn Total	Dust	HCl	HF	SO_2	NO_x
Western Germany[1]	20	30	25	No Limits	100	100	5	100	—
Switzerland[2]	Cd = 0.1 Hg = 0.1	Pb + Zn = 5			50	100	5	500	—
Netherlands[3]					100	1000	20	600	—
France					150				
Great Britain					270-460	460			
Japan					100-200	430			

(values are in moist gas related to 11% O_2)

[1] TA Luft

[2] recommendations

[3] general directions

It should be recognized that above standards are issued by federal authorities as maximum values not to be exceeded. Local authorities always have the power to set lower limits.

enormous progress of the chemical analysis technique.

This tendency can be found in the hitherto known emission limits (Table 1). All countries mentioned in this table have limits for the emission of dust. Only some of them have limits for gaseous compounds too. Binding limits for the emission of heavy metals fail – with the exception of Germany – completely!

Treatment of the Flue Gases

The separation of the flyash starts already in the boiler.

Finer dust can be eliminated in the electrostatic precipitator. It must be emphasized, however, that an electrostatic precipitator only separates fine dust particles, but no gaseous compounds. A reduction of the gaseous pollutants is not possible with an electrostatic filter only, but requires also the installation of a flue gas scrubber.

For a long time it was assumed that the problem of gaseous pollutants can be reduced by means of the height of the stack. It is evident that with a higher stack the distribution distance of the pollutants becomes longer. But there is no reduction of the emission itself. There is only a displacement of the zone of emission.

Today, practically all incineration plants in Europe are equipped with dust precipitators. In Germany, the country with the largest number of municipal waste incineration plants, about one third of these plants is additionally also equipped with flue gas scrubbers. The scrubbers were either installed from the beginning on, as is the case with newer plants, or they were installed later and in addition to the already existing electrostatic precipitator. Today, no new municipal or industrial incineration plant will be built without also a flue gas scrubber for the removal of gaseous pollutants.

In general, two basic scrubber systems are used in Europe, the wet scrubbers using a washing fluid containing the chemical reaction compounds in solution, and the dry scrubbers, where the chemical reaction compounds are sprayed into the flue gas in the form of a powder or a slurry.

Table 2 shows the municipal waste incineration plants in Germany which are equipped with flue gas scrubbers.

The history of the development of new processes for the reduction of gaseous emissions from waste incineration plants in the last 12 years is rather interesting.

Once the problem of the gaseous pollutants was recognized, the well-known unit operations for wet gas absorption such as packing towers and plate towers were applied. The reduction of

Municipal Waste Incineration Plants in Germany, Equipped with Flue Gas Scrubbers

Table 2

Location	No. of Scrubbers	Type of Scrubber	Effluents	Gaseous Pollutants Separated	1 Year of Operation
Bamberg	2	wet	a	HCl, HF	1978
Bremerhaven	3	wet	a	HCl, HF	1977
Düsseldorf	1	dry	—	HCl, HF, SO_2	1981
Frankfurt	4	dry	—	HCl, HF, SO_2	1984
Hamburg I	4	dry	—	HCl, HF, SO_2	1981
Hamburg II	2	dry	—	HCl, HF, SO_2	1978
Hamburg III	2	wet	b	HCl, HF, SO_2	1979
Ingoldstadt	2	wet	a	HCl, HF	1978
Iserlohn	c	wet	b	HCl, HF, SO_2	c
Kempten III	1	dry	—	HCl, HF, SO_2	1983
Kiel-Süd	3	wet	a	HCl, HF	1976
Krefeld	2	wet	a	HCl, HF, SO_2	1976
München-Nord	1	dry	—	HCl, HF, SO_2	c
Neustadt	1	wet	b	HCl, HF, SO_2	1984
Pinneberg	1	dry	—	c	1978
Schwandorf	3	dry	—	HCl, HF, SO_2	1984
Wuppertal	2	wet	a	HCl, HF	1978
Würzburg	2	dry	—	HCl, HF, SO_2	1983
Zirndorf	2	wet	a	HCl, HF	1978

a = effluent treatment plant and discharge into sewer
b = evaporation of effluents, no discharge to outside
c = no data available

Correction to page 15, Energo '83 Conference Papers.

the emission of the gaseous pollutants to the required limits with these unit operations was possible. It was also realized that the treatment of the flue gases from waste incineration plants has to be done in two steps:

- in a first tower with an acidic washing fluid, the reduction of hydrochloric acid and hydrofluoric acid occurs.
- for the reduction of sulphur dioxide, a second tower with an alcaline washing fluid is necessary.

But soon it became apparent, too, that in this way the reduction of gaseous pollutants was solved, however, at the cost of a high water pollution, which was not intended at all.

So, theoretical considerations and pilot plant tests began to point towards a dry process for the flue gas treatment. Chemicals in dust form such as slaked lime or dolomite were blown into the flue gas stream. The small particles absorbed the noxious gases at their surface and were caught themselves by an electrostatic precipitator or in a bag house. The efficiency of these dry processes is not as high as with wet processes, but there is no water pollution problem.

So the object of the further development was a

Processes for the Reduction of Gaseous Emissions from the Flue Gases of Incineration Plants

Table 3

Process	**Wet Scrubber with treatment of the Effluent Waste Water**	**Wet Scrubber Followed by Evaporation of Water**	**Injection of Lime Slurry with Evaporation of the Water in the Hot Flue Gas**	**Injection of Dry Dust**
Type of Reaction	Absorption Processes		Adsorption Processes	
Waste Water	Special Treatment	Processes Without Waste Water		
Supplement Energy Consumption kWh/t Waste	11-20	22-40	12-21	8-20
Consumption of Chemicals per t of Waste	Approx. 12 kg $Ca(OH)_2$ + Approx. 5 kg NaOH	Approx. 13 kg $Ca(OH)_2$ + Approx. 5 kg NaOH	21-35 kg $Ca(OH)_2$	20-40 kg $Ca(OH)_2$
Remaining Emissions at Stack (mg/Nm³, wet gas, 11% O_2)				
HCl	10-30		40-60	50-100
HF	0.5-2		0.5-3	3-5
SO_2	Approx. 100 (two steps) Approx. 300 (one step)		200-300	400-600
Dust				
• with electrostatic precipitator	Less than 30*		30-80	30-80
• with baghouse filter	Less than 30*		Less than 30	Less than 30
Total of Heavy Metal Including Gaseous Emissions				
• with electrostatic precipitator	1-2*		2-4	2-4
• with baghouse filter	Approx. 1		Approx. 1	Approx. 1
Temperature of the Cleaned Flue Gases	Saturation Temperature (65-70°C)		80-120°C Below the Temperature of the Raw Gas	5-20°C Below the Temperature of the Raw Gas
Recommendation	Preferably for New Plants, Not Recommended for Supplementary Installations		Possible as Supplementary Installations in Existing Plants	

*) some scrubber systems achieve these values without the application of an electrostatic precipitator or a baghouse filter

Correction to page 16, Energo '83 Conference Papers.

Location	No. of Scrubbers	Guaranteed Separation of	System	1st Year of Operation
Biebesheim, Germany	2 wet	HCl, HF, SO$_2$, heavy metals dust	VonRoll/ Ciba-Geigy	1982
Herten, Germany	1 wet	HCl, HF, SO$_2$ dust	Saarberg/ Hölter/Lurgi	1982
Norrtorp, Sweden	1 dry	HCl, HF, SO$_2$	Niro	1983
Nyborg, Denmark	1 dry	HCl, HF, SO$_2$ SO$_3$, dust 2nd unit	Niro	1982

flue gas cleaning process with high efficiency, but without waste water problems.

Using wet scrubbing processes, ways were looked at for the evaporation of the effluent washing water without additional energy consumption. At present it seems that the processes with spray towers for the evaporation of the effluent water using the hot raw flue gas as energy source have some advantages over multi-stage evaporators.

The dry processes were improved, too. The injection of the reactants in dry form was replaced by the injection of lime slurry in the hot flue gas stream. The water of the slurry evaporates immediately, and on the surface of the fine particles formed the gaseous pollutants are better adsorbed. In addition the solid particles of the slurry burst by the sudden evaporation of the water, and thereby smaller particles with a big surface are formed.

The efficiency of these – so to speak – dry processes seems to be better than that of the classic dry process.

A short survey of the four processes described above is given in Table 3.

It is evident that the adsorption processes have some disadvantages (lower efficiency, higher consumption of chemicals). Their advantage, however, lies in the fact that their supplementary installation in an existing waste incineration plant is much easier.

On the other hand, it cannot be denied that for new plants and especially in the light of a future lowering of the emission limits, the treatment of the flue gases with wet processes followed by an evaporation of the water and with dry extraction of the bound pollutants has a real chance.

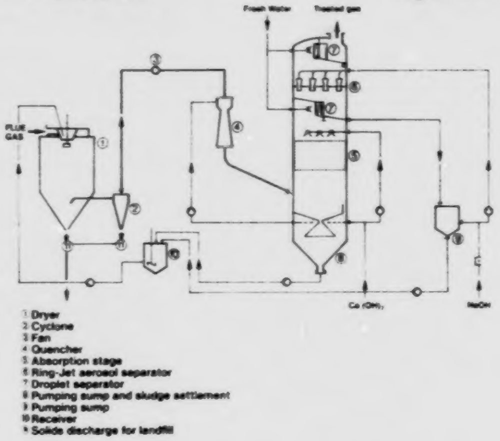
The modern technology of effluent-free scrubbers is of course also applied in the most recent industrial waste incineration plants particularly in the regional disposal centers which have to handle the whole range of solid, semi-solid and liquid industrial waste.

The Von Roll/Ciba-Geigy system, which is in operation in an industrial waste incineration plant operated by the H.I.M. (Hessische Industriemüll GmbH) in Biebesheim, south of Frankfurt, can today be considered as the system with the highest removal efficiency.

The following flow diagram describes briefly its function.

Ciba-Geigy/Von Roll Process

figure 9



The hot flue gases are cooled in the dryer through contact with the scrubber effluent containing solids and insoluble and soluble salts. In this way, all the pollutants contained in the effluent are converted to a dry, free-flowing solid residue which is extracted from the dryer and the downstream cyclones. Most of the fine dust contained in the flue gas is also removed in this stage.

In a downstream gas quench unit the flue gas is cooled, but not below the dew point. Acidic gases such as HF and HCl are absorbed in the quench stage and also in the subsequent absorption stage. The absorption stage is packed with so-called hedgehog packing, which provides a large contact area for mass transfer and ensures adequate conditioning prior to the removal of aerosols. The pH of the absorption liquor is maintained slightly acidic.

The aerosols, which are condensed during the cooling process, and the fine dusts, are eliminated in a separate stage equipped with specially designed so-called "ring-jet" elements.

If required, SO_2 can also be efficiently removed in the aerosol removal stage by pH control using a sodium hydroxide addition.

The principal features of this effluent-free flue gas treatment system can be summarized as follows:

- needs no electro-filter
- removes pollutants in the form of a mobile ash
- guarantees high purification efficiencies by the selection of effective scrubbing equipment
- uses inherent heat capacity of flue gas to evaporate scrubbing effluent
- requires less than stoichiometric quantities of neutralizing chemicals (NaOH; $Ca(OH)_2$).

Conclusion

Two tendencies on the pollution side, as far as the legislation is concerned, can be recognized in Europe. First, the air pollution laws are becoming more and more stringent and second, the same goes for the water pollution limits.

In practically all highly industrialized countries in Europe therefore, no new waste incineration plants will be built anymore without installing also a scrubber for the removal of gaseous pollutants from the flue gas. Furthermore, new laws are either already in force or at least on their way, which will also induce existing waste incineration plant operators to add flue gas scrubbers to their installations. And if a wet scrubber system is chosen, an effluent water treatment facility will have to be provided as well.

It appears quite understandable, therefore, that dry scrubbers and effluent-free wet scrubbers will be the systems of the future. And experience also has shown that whenever new developments have finally proved to reliably meet more stringent limits than the standards are asking for, these standards will be lowered accordingly.

References

1 The papers of this symposium will be published by Ann Arbor Science Publication in 1982

2 Cremer, H: "Zur Reaktionskinetik der Methan-Oxidation" Chem.-Ing.-Techn. 44, 8 (1972)

3 Paauw, Th. T.A. et al: "Die Bildung von Stickstoffoxiden bei industriellen Erdgasverbrennungsprozessen" VDI-Report No. 364, 55 (1979)

4 Gardiner jr. W.C.: "The Chemistry of Flames" Scientific American, February 1982

5 Gardiner jr. W.C. ibid.

6 Buser, H.R. and Bosshard, H.-P. Mitt. Gebiet Lebensm. Hyg. 69, 191 (1978) Chemosphere 7, 165 (1978)

7 Dow Chemical Company: "The Trace Chemistries of Fire – a Source of and Routes for the Entry of Chlorinated Dioxins in the Environment (1978).

8 LIS Bericht Nr. 17: "Dioxin-Emissionen aus Müllverbrennungsanlagen" Landesanstalt für Immissionsschutz des Landes Nordrhein-Westfalen, Essen, 1982

9 Schriftenreihe Umweltschutz Nr. 5: "Umweltbelastung durch Dioxine une Furane aus kommunalen Kehrichtsverbrennungsanlagen" Bundesamt für Umweltschutz, Bern, 1982

Use of Refuse Derived Fuel as a Supplementary Fuel in Cement Kilns

by:
A. F. Robb
and R. Luka
Canada Cement Lafarge Ltd.
A Joint Ontario Government – Industry Project

Abstract

Waste is, by definition, material which has no practical value, and the problem it poses to municipalities is one of disposing of it in the least costly manner. Some raw materials and sources of energy, in particular, are in short supply or are becoming increasingly expensive. What we call waste, may be of value to some industry. The problem now is one of recovering components that are usable either as fuel or as recycled raw materials.

To show if part of recycled materials from municipal refuse can be used as supplementary fuel in cement kilns, the Ontario Ministry of the Environment built an Experimental Plant for Resource Recovery. The light fraction from this Recovery Plant was used for a "Field Test" at the Woodstock plant of Canada Cement Lafarge Ltd. to establish:

1. The equipment designed for shredding and conveying RDF to the kiln is functional with respect to delivery and feed control.
2. To determine if RDF can be used as a partial kiln fuel substitute and the extent of substitution.
3. To determine the effect of RDF ash on cement quality. Similarly to determine any adverse effects due to emissions from kiln stacks.

Introduction

In October 1974, the Province of Ontario announced a comprehensive solid waste management program. One of the three objectives of this program was to provide a regular supply of recovered resources for product utilization.

The municipal refuse, 40% of which consists of paper, film plastic and minor amounts of organic material is known as "light fraction". This fraction could represent a source of energy, having half the calorific value of coal. Due to its suitability as a fuel, it is frequently referred to as "Refuse Derived Fuel" or RDF. Low calorific value, high moisture content and rather coarse fineness make this material suitable to be used as a supplementary source of heat for a cement kiln.

Some people are under the misconception that "anything" can be used as a fuel in a cement kiln. This is not correct. As care must be taken in the selection of raw materials and the preparation of raw feed for a kiln, care must also be taken in the evaluation and selection of a fuel. Some fuels might produce heat in an uneven manner causing damage to protective scale and refractory lining of the kiln. The result might also be cycles of hot and cold conditions that produce uneven quality in the clinker. Undesirable chemicals in the exit gas might produce build up of material at the feed end of the kiln. Undesirable chemicals in the ash will adversely effect product quality. Each fuel has to be assessed regarding its effect on operator health and safety, on the environment and on the quality of the product.

To verify the viability of RDF as a partial substitute for primary kiln fuel, Canada Cement Lafarge Ltd. in 1976, entered into an agreement with the Ontario Ministry of Environment, Resource Recovery Branch to do a "Field Test" of burning RDF. During this test, the primary fuel was coal.

Basically, the agreement consisted of the Resource Recovery Branch building a facility at the Woodstock plant to shred and convey the RDF to one of the cement kilns. The Ministry also supplied the RDF for the test. The Company was responsible for the operation of this facility and the kiln during the test, and the product quality. The Ministry of the Environment was responsible for kiln stack emissions testing.

Conclusions

For the "Field Test" done with RDF as partial substitute for kiln fuel, positive and negative statements can be made. From the experience gained during this period, it must be said that the design and equipment specifications must be considered very carefully if permanent facilities are installed and continuous use of RDF considered. Refuse Derived Fuel (RDF) is a material with which cement people have little or no experience. When any new fuel is introduced to a cement kiln there is a period of acclimatization for kiln operators that may extend for a few months.

The RDF is a material which is very difficult to handle. The many problems experienced during this test were with material handling and malfunctioning of equipment. It was found during one of the preliminary tests, that all hoppers had to be inverted, i.e. the bottom of the hoppers had a greater dimension than the top of the hoppers. If not, the material would bridge. Hoppers with vertical sides are not adequate to prevent plugging. Another serious problem with equipment was improper choice of shredder hydraulic drives. The shredder had three sets of cutting knives with individual drives and in the three week period, all three drives failed. During the operation these drives were partly the cause of irregular feed rate of RDF. The shredder, because of its design, was susceptible to material build-up above the knives. Due to hopper design and shredder plugging with material, extra supervision at all times was required at this location. The great fluctuations of RDF passing through the hopper and the shredder prevented the weigh belt from functioning properly. The Radar Feeder, too, stopped the operation on several occasions when a very small piece of metal jammed between the housing and the blades.

The material was delivered to the plant from Toronto in bales; the bales were then unloaded and stored on the ground. Since this is a pilot facility, no cover was available to protect the bales from rain, snow or frost. As a result of this type of storage, on occasion it was impossible to loosen the material so it could be shredded. Baling of RDF is not only expensive but promotes severe compaction. There are alternate means of handling RDF. Baling was chosen because of storage and transportation constraints associated with the test project. (A short test of less than 8 hours using unconsolidated RDF was conducted. There seemed to be fewer material handling problems with this test.)

From the comments above, it can be seen that design of equipment for handling RDF should be such that passage of material from storage to kiln is unhindered. It must be stressed strongly, that control of fuel feed rate to a cement kiln is very critical. Even a short period of fuel interruption will result in cooling conditions and lower kiln production. Handling of RDF should be in bulk form to minimize labor required and lessen exposure to the material even though there are no safety hazards. Since bulk material would always be covered, changes in the moisture content would be minimized. Moisture content varied from 14% to 24% during the test.

Although coal was used as a primary fuel during this test, natural gas and bunker oil could also be used. Chemistry of raw mix can also be adjusted to account for ash from the RDF. There are variations in the ash content in the RDF, but with a reserve of RDF fuel, and continuous control of raw mix and clinker, no serious problems should arise from this.

The chemical properties of clinker and cement produced with RDF and without RDF show no significant differences (Tables 1, 2, 3).

The physical properties of cement appear to be comparable to non RDF cement. The compressive strengths of cement (Table 4) produced from RDF clinker are lower but this may be partially due to clinker exposed to moisture during the storage. No covered storage for clinker is available. Previous tests done showed similar loss in compressive strengths.

The particulate emission testing showed that generally the emission increased from 0.364 lb/ton to 0.861 lb/ton which frequently produced visible emissions from the stacks. The higher emission level using RDF is still well within the emission guidelines of 1.6 lb/ton. Since additional testing could not have been done at higher RDF usage, emission levels at higher usage levels would have to be determined.

Stack emission tests have been done for SO_2 and NO_x. These are shown in Table 7. Since the equipment malfunctioned during base line for coal firing only, SO_2 and NO_x data obtained in March 1979 is included for comparative purposes.

Fluctuations in the RDF feed to the kiln, as can be seen in the wide variations in percent oxygen at the feed end of the kiln (Table 6) caused the kiln production rate to drop by an average of 10%. This is significant.

Immediate use of RDF as a supplementary fuel at Woodstock is not practical. Problems with plant design, equipment and material handling methods have been identified. The existing test plant will not be adequate as a production facility. More testing would have to be done and much more capital would have to be invested, particularly in storage and material handling facilities, in order to establish an adequate fuel firing system. In light of the limited RDF generating capacity in Ontario, the distance of Woodstock from the current sole facility and the uncertain cost of this fuel, Canada Cement Lafarge Ltd will not be proceeding further with RDF at this time.

Our company is very interested in any form of supplemental fuel however and is currently conducting tests with shredded rubber tires, fluidized coke and liquid hydrocarbon by-products.

General Description of the Cement Plant (Fig. 1, 2)

The Canada Cement Lafarge Ltd. Woodstock plant has a nominal cement production capacity of 525,000 tonnes. Seven different types of cement are produced on routine basis. The two major raw materials, namely limestone and clay, are quarried from the company property located near the plant. Additional minor raw materials such as sand and iron oxide are purchased as required.

The company operates two wet process kilns. These are F. L. Smidth, 12 foot by 450 foot, each producing 700 tonnes daily. The plant is capable of using a variety of fuels, natural gas, coal or a combination of natural gas and petroleum coke. Facilities will be installed to enable the plant to use liquid fuels. With this type of versatility, this plant will be able to take advantage of the lower cost fuel materials.

Each kiln is equipped with a F. L. Smidth # 22 x 4.0 x 3.2 m Tirex coal mill. These mills have three compartments, one which is a drying chamber and the other two grinding chambers. Hot air from the clinker coolers is used for drying and conveying the coal through the mills and used as primary air. This is a direct firing system where the amount of coal required for the kiln firing is controlled by a damper on the outlet of the mill. Milltronic Audio system controls the feed rate of the mill. In this manner, the mills not only grind the coal but also act as storage for pulverized coal. Coal fineness as introduced to the kilns is 85% passing 200 mesh.

The kilns are equipped with 4-compartment, 8 section Joy Electrostatic precipitators, each having a capacity of 200,000 c.f.m. Dust from the front two compartments is returned to the kilns, whereas the dust from the last two compartments is wasted. Wasting of dust is necessary to prevent alkali concentration build-up in the system.

Since this is a wet process operation, raw mix or slurry, as it is commonly known, is produced with three ball mills. Two of these are 1100 horsepower and the third is 1000 horsepower. The total capacity is approximatley 120 tonnes per hour, with the fineness of the slurry at 89.0% ± 1% passing 200 mesh and the moisture content at 31.5% ± 0 – 5%. The slurry is stored in a basin having a capacity of 5000 tonnes or 6 silos each having a capacity of 285 tonnes.

Description of the RDF Facility (Fig 3, 4)

This facility, built in 1977, may not be unique, but it was conceived to receive, shred, meter and pneumatically convey the quantities of RDF as required to the kiln. Due to the experimental nature of this project, certain equipment malfunctioned during the test. The consulting engineer, selected to design this pilot facility, had designed the refuse separation plant in Toronto. That plant was in the early stages of being "debugged". Both facilities suffered from a lack of experience in handling RDF. Also, the choice of baled RDF proved to be difficult to handle. For this project, baled material was specifically chosen for the following reasons:

- no storage was available for unconsolidated material
- a continuous supply of RDF was required
- sufficient transfer vehicles for unconsolidated material were not available.

The baled RDF was fed to the facility by putting the bales on a receiving platform with a fork truck. The three strands of wire, 8 gauge, were cut manually, removed and fed into the wire chopper. The bottom of the receiving hopper was hydraulically opened, permitting the loose RDF to fall onto a 48 inch by 65 foot conveyor belt, driven by a 20 H.P. motor. This belt is totally enclosed and capable of holding 8 bales, each weighing 800 pounds.

The material from the conveyor was discharged on to a pair of spike-rollers. RDF, when stored in bales, forms blocks of material when the bales are cut apart. The spike-rollers separated these blocks of material into its original density. The belt conveyor and the spike-rollers are controlled by photo-cells, measuring the amount of material over the shredders.

The material from the spike-rollers was discharged into a "Shred-Pax" Model AZ-15-3 shredder. This unit has an effective cutting area of 25" x 48" and can handle seven tons per hour of pre-shredded paper and cellulose material.

The shredder contains three sets of single speed revolving cutting knives, 8" in diameter and 1-3/16 inch thick. The unit was driven by three hydraulic drives, each powered by C.G.E. 15 H.P. Induction motors. Through this drive feed discharge rate is controlled, the direction of the cutting knives can be reversed if plugging occurs or one unit may be shut down completely if so required.

The shredded material, which was minus 2 inch, discharged on to a 48" wide and 15 foot long weigh conveyor. This is a Merrick 450 DS – 1 unit driven by a 1 H.P. motor. The weighometer unit is a temperature compensated strain gauge load cell. In a closed loop with the load cells, the DS – 1 Digital Weigh system was to control the speed of the shredder. The Digital Weigh system did not function properly due to great variations in the shredder output which was beyond the limits of weigh belt control. Therefore the shredders were operated on manual control.

The material from the weigh conveyor was discharged through a Radar Feeder into the air-veying system. The Radar Feeder, 25" x 30" and driven by a 5 H.P. motor acted as an air lock. The air-veying system consists of a blower, supplying 8000 cfm of air and an 8 inch pipe line 400 feet in length. The burner pipe was 8 inch S.S. schedule 40 pipe, extending 1 foot into the kiln. The burner pipe was directed so that the material (RDF) entering the kiln would join the coal flame. This design was chosen rather than one with concentric RDF and coal pipes, due to the short duration of the test.

RDF Material

RDF (Refuse Derived Fuel) is the air classified paper and cellulose fibre fraction of shredded municipal solid waste. It also contains light plastics, some wood, cloth and some organic material. The maximum size of this material was 6 inch and delivered to the plant in 30" x 48" x 60" bales. Based on a sample analysis at the Resource Recovery Centre, each 800 pound bale contained approximately:

400 pounds of paper

60 pounds of plastics, wood and cloth

200 pounds of combustible and inert fine material (dust)

140 pounds of moisture (17.4%)

Since this was a pilot facility, no protection of the bales against rain or snow was available. Therefore the moisture of the RDF varied considerably depending on the amount of precipitation.

Refuse Derived Fuel, RDF

The RDF used during this period varied in calorific value, % Moisture and % Ash

	AS RECEIVED			
DATE	MJ/t	BTU/lb	%H_2O	%Ash
April 11/80	14675	6310	16.6	17.4
April 13/80	14332	6162	17.1	19.7
April 17/80	13097	5631	20.5	21.0
April 18/80	14469	6221	16.9	17.8
April 19/80	12630	5430	24.0	22.8
April 20/80	13916	5983	20.9	18.65
April 21/80	14015	6026	15.3	20.9

Similar information for coal as shown above for RDF is

Calorific value – 31585 MJ/t
– 13581 BTU/lb
Moisture – 7.5%
Ash – 6.96%
Sulfur – 3.06%

The calorific values shown above are High Heat values. A factor of 0.98 was assumed for Low Heat value which is similar to the LHV factors for coke and coal.

Samples of RDF and RDF ash were taken and analyzed by the Ministry of the Environment – Air Quality Section for a wide range of elements and compounds. The ash analyses of both coal and RDF are listed in Table 8.

Field Test

The "Field Test" using RDF as partial substitute for coal was done during the period of April 7-25, 1980. The testing was further continued, but with coal only, until May 1, 1980.

Before proceeding into the discussion of the test itself, it should be mentioned now that there were numerous problems throughout this period. Malfunctioning of RDF equipment and severe changes in the weather were both conditions effecting the optimum operation of the kiln. Problems such as continuous plugging of the hopper over the shredder resulted in varying feed rate to the kiln. Mechanical problems with the hydraulic drives posed similar problems with the feed rate. Due to lack of protection against rain and snow and freezing conditions, separation of material in the bales was most difficult. However, there were periods of steady RDF supply. The longest period of this steady supply was two hours. Over the duration of the test the kiln did operate in a steady manner, from time to time, but only at reduced production levels which enabled the operators to cope with the erratic supply of RDF.

Generally, the following routine was used during the test. Since Type 10 clinker was being produced, the raw feed to the kiln had to be adjusted to account for the ash from the coal and the RDF.

The bales of RDF were delivered to the plant on a daily basis by truck. Upon weighing and counting of bales, the average weight of the bales was determined and recorded. The bales were then unloaded with a fork truck near the RDF facility. During the burning of RDF, which was on a continuous basis, the bales were put on the receiving table, baling wire cut, the loose material then proceeded up the conveyor belt to the spike rollers. The spike rollers would further loosen the material and pass it on to the shredders. Once the material was shredded down to minus 2 inch size, it was conveyed on the weigh belt to the Radar Feeder. Finally it was conveyed in the air-veying system to the kiln.

When RDF was introduced to the kiln, a corresponding reduction in the amount of coal took place in order to maintain constant oxygen and constant feed end gas temperature. The RDF was conveyed using 8000 cfm of cold (ambient) air. This cold primary air partially offset the heat benefit of the RDF. When RDF supply was interrupted, as explained earlier, the continuing flow of cold air had a cooling effect on the burning zone of the kiln creating heat/cold cycles. This cold air supply had a doubly adverse effect on the kiln as it displaced hot secondary air that would normally be recovered from the clinker cooler.

Sampling and Testing

Throughout the RDF test period of four weeks, clinker produced was analyzed (Table 2) on a daily basis. The chemical analysis of the daily clinker shows no abnormalities. Although the liter weights (Table 6) varied considerably, the daily results of F-CaO show that well burned clinker was produced. One criteria of this test was to produce clinker of good quality. In order to achieve this with the erratic supply of RDF it was necessary to operate the kiln at a lower production rate. The cement produced from RDF burned clinker showed no serious changes in the chemistry of the cement (Table 2). The physical properties of the cement (Table 4) show that compressive strengths are lower. This may be due to the variations in the burning of the clinker and also to the weathering of the clinker prior to grinding. Previous short run RDF tests done at this plant (July/79 and Dec/79) showed similar decrease in compressive strengths. At 20% RDF substitution, there appears to be a decrease of 7% in strengths.

Stack emissions have been done, with the results shown on Table 5. The particulate emissions have increased during RDF burning. Out of 8 tests attempted, only 5 were completed. There were fluctuations in the fuel input, which resulted in the oxygen, and tripping out of the precipitator.

Tests for SO_2 and NO_x (Table 7) were also done on April 16, 17 and 18, 1980 during RDF burning. On April 30 and May 1, 1980 during which time only coal was used, the testing equipment malfunctioned, so the results can not be considered. Data for March 20-22, 1979 is shown for coal burning only and as base line data. Emissions of these compounds depend greatly on the degree of burning. One of the major problems during the test was uneven fuel supply which resulted in uneven burning.

RDF and Coal – Clinker Analysis

Table 1

**CANADA
CEMENT
LAFARGE LTD.**

APRIL 8/80 – MAY 1/80

T10

RDF & COAL "TEST BURN"

1980	RDF USED	101	102	103	104	105		106	107	108		RATIOS			CALCULATED COMPOUNDS						ADDITIONAL DATA OR REMARKS				
DATE	TONNES	SiO_2	Al_2O_3	Fe_2O_3	T-CaO	F-CaO	C-CaO	MgO	SO_3	LOSS	TOTAL	LR	SR	AR	C_4AF	C_3A	C_3S	C_2S	SrO	TiO_2	PbO	ZnO	P_2O_5	CuO	Mn_2O_3
APR 7																									
8																									
9																									
10																									
11																									
12																									
13																									
14																									
15		23.00	4.53	2.93	64.49	0.50	63.99	2.86	0.60	0.21	98.62	2.11	3.08	1.54	8.9	7.0	53.0	26.0	0.04	0.23	0.00	0.01	0.07	0.01	0.03
17	14.86	22.91	4.55	3.11	64.50	0.50	64.00	2.76	0.72	0.12	98.67	2.10	2.99	1.46	9.5	6.8	53.4	25.5	0.03	0.21	0.00	0.01	0.11	0.01	0.04
17	12.00	22.77	4.58	3.16	64.03	0.64	63.39	2.87	0.92	0.10	98.43	2.09	2.94	1.44	9.6	6.8	52.2	26.0	0.03	0.21	0.00	0.01	0.10	0.01	0.05
18	10.44	22.35	4.62	3.51	63.31	0.92	62.39	2.94	1.09	0.15	97.97	2.07	2.74	1.31	10.7	6.3	51.7	25.1	0.03	0.21	0.00	0.01	0.10	0.01	0.05
19		23.09	4.53	2.73	64.56	1.03	63.53	2.94	0.60	0.10	98.55	2.12	3.18	1.65	8.3	7.4	52.9	26.4	0.03	0.22	0.00	0.01	0.09	0.01	0.05
20	12.25	22.60	4.58	2.56	64.80	0.56	64.24	2.84	0.69	0.10	98.19	2.17	3.16	1.78	7.8	7.8	57.5	21.5	0.03	0.21	0.00	0.009	0.12	0.07	0.05
21																									
22												**Alkalies:**	Na_2O	K_2O											
23												Apr. 15/80	0.58	0.54											
24												Apr. 17/80	0.62	0.79											
25												Apr. 17/80	0.78	0.71											
												Apr. 18/80	0.85	0.87											
AVE.												Apr. 18/80	0.48	0.43											
												Apr. 20/80	0.75	0.64											
											COAL ONLY – CLINKER ANALYSIS														
APR 29	Nil	22.57	4.24	2.89	64.68	0.84	63.84	2.91	1.15	0.14	98.58	2.17	3.16	1.46	8.8	6.3	59.1	20.2	0.03	0.18	0.00	0.008	0.11	0.005	0.03
30	Nil	22.60	4.25	2.83	64.98	0.64	64.34	2.80	1.01	0.11	98.58	2.18	3.19	1.50	8.6	6.5	60.1	19.5	0.04	0.19	0.00	0.007	0.11	0.005	0.03
MAY 1	Nil	22.50	4.27	2.79	65.00	0.36	64.64	2.84	1.08	0.15	98.63	2.19	3.18	1.53	8.5	6.6	60.9	18.7	0.03	0.19	0.00	0.006	0.11	0.005	0.03
												Alkalies:	Na_2O	K_2O											
AVERAGE												Apr. 29/80	0.55	0.82											
MAXIMUM												Apr. 30/80	0.66	0.84											
MINIMUM												May 1/80	0.60	0.65											
STD DEV																									

RDF and Coal – Clinker Analysis

Table 2

CANADA CEMENT LAFARGE LTD. **APRIL 8/80 – MAY 1/80** **T10** **RDF & COAL "TEST BURN"**

1980	RDF	101	102	103	104	105		106	107	108		RATIOS			CALCULATED COMPOUNDS						ADDITIONAL DATA OR REMARKS				
DATE	USED TONNES	SiO_2	Al_2O_3	Fe_2O_3	T-CaO	F-CaO	C-CaO	MgO	SO_3	LOSS	TOTAL	LR	SR	AR	C_4AF	C_3A	C_3S	C_2S	SrO	TiO_2	PbO	ZnO	P_2O_5	CuO	Mn_2O_3
APR 7																									
8	38.433	23.97	3.81	3.65	64.31	0.64	63.67	3.51	0.25	0.15	99.65	2.04	3.21	1.04	11.1	3.9	48.7	32.0	–	–					
9	43.134	22.97	4.37	3.41	63.64	0.50	63.14	3.84	.72	.08	99.03	2.06	2.95	1.28	10.4	5.8	50.2	28.1	0.03	0.20	0.000	0.01	0.04	0.01	0.03
10	41.475	22.70	4.59	3.32	63.43	0.78	62.65	3.59	0.55	.10	98.28	2.07	2.86	1.38	10.1	6.5	50.0	27.4	0.04	0.23	0.000	0.01	0.06	0.01	0.05
11	38.367	22.70	4.49	3.19	63.95	0.87	63.08	3.31	73	.12	98.49	2.10	2.95	1.40	9.7	6.5	53.0	25.2	0.04	0.22	0.000	0.01	0.07	0.01	–
12	42.753	22.65	4.56	3.20	63.43	0.84	62.59	3.44	.57	.12	97.99	2.08	2.91	1.42	9.7	6.7	50.8	26.7	0.04	0.22	0.000	0.01	0.08	0.01	–
13	41.656	22.65	4.60	3.10	64.06	0.56	63.50	3.20	.38	.12	98.11	2.11	2.94	1.48	9.4	6.9	53.2	24.9	0.03	0.22	0.00	0.01	0.05	0.01	–
14	45.633	22.32	4.56	3.12	64.33	0.50	63.83	3.79	.33	.11	98.56	2.14	2.90	1.46	9.5	6.8	57.1	21.0	0.04	0.22	0.00	0.01	0.07	0.01	0.04
15	13.522	22.30	4.62	3.35	64.17	0.65	63.82	3.72	.58	.12	98.86	2.11	2.79	1.37	10.2	6.6	55.8	21.9	0.04	0.23	0.00	0.01	0.07	0.01	0.05
16	13.782	22.38	4.38	3.58	63.35	0.78	62.87	3.38	.93	.15	98.13	2.08	2.81	1.21	10.9	5.5	53.3	24.0	0.03	0.23	0.00	0.01	0.06	0.01	0.05
17	43.891	22.27	4.67	3.20	63.54	1.73	61.81	3.62	.91	.12	98.33	2.10	2.82	1.45	9.7	7.0	53.4	23.6	0.03	0.21	0.00	0.01	0.06	0.01	0.04
18	23.186																								
19	21.073	22.85	4.71	3.09	64.47	0.81	63.66	3.78	.58	.12	99.60	2.10	2.92	1.52	9.4	7.2	52.7	25.9	0.03	0.22	0.00	0.01	0.12	0.01	0.04
20	69.671	22.36	4.62	3.04	64.42	0.56	63.86	3.70	.57	.15	98.86	2.14	2.91	1.51	9.2	7.1	56.8	21.3	0.03	0.22	0.00	0.01	0.09	0.01	0.04
21	49.193	22.32	4.86	3.25	63.72	0.98	62.73	3.49	.81	.14	98.56	2.09	2.75	1.49	9.9	7.4	52.4	24.6	0.03	0.22	0.00	0.01	0.08	0.01	0.04
22	45.956	22.58	4.74	2.84	63.66	0.75	62.91	3.22	.97	.11	98.10	2.11	2.97	1.66	8.6	7.8	51.7	25.7	0.04	0.22	0.00	0.01	0.10	0.01	0.04
23	55.815	22.82	4.65	2.74	63.97	0.53	63.44	3.18	.67	.12	98.19	2.11	3.07	1.67	8.4	7.6	51.7	26.5	0.03	0.22	0.00	0.02	0.11	0.04	0.03
24	39.010	22.65	4.43	2.75	63.10	0.39	62.71	3.37	1.28	.12	97.70	2.11	3.15	1.61	8.4	7.1	51.0	26.6	0.04	0.22	0.00	0.00	0.11	0.01	0.03
25	31.305	22.46	4.65	2.59	63.50	1.37	62.13	3.34	1.35	.12	98.22	2.12	3.01	1.66	8.5	7.6	52.5	24.9	0.00	0.22	0.00	0.01	0.10	0.01	0.03
AVE.																									
	604.13																								
										COAL ONLY – CLINKER ANALYSIS															
APR 29	Nil	22.32	4.56	3.00	64.07	0.50	63.57	3.29	0.90	0.16	98.30	2.14	2.95	1.52	0.91	0.70	56.2	21.7	0.03	0.22	0.00	0.00	0.11	0.07	0.03
30	Nil	22.60	4.43	2.86	64.72	0.75	63.97	2.98	0.92	0.15	98.66	2.16	3.10	1.54	0.87	0.69	57.8	21.3	0.03	0.22	0.00	0.00	0.11	0.07	0.02
MAY 1	Nil	22.41	4.55	3.01	64.17	0.51	63.66	3.29	0.92	0.15	93.50	2.14	2.96	1.51	0.92	0.70	56.0	22.1	0.03	0.22	0.00	0.00	0.11	0.06	0.03
AVERAGE																									
MAXIMUM																									
MINIMUM																									
STD DEV																									

Chemical Test Results for Cements

Table 3

Test	1	2	3
Clinker			
% RDF used	20	20	0
Cement			
% RDF Clinker Used	50	100	0
% Coal Clinker Used	50	0	100
Insol	0.14	0.14	0.14
SiO_2	21.77	21.83	22.31
Al_2O_3	4.27	4.31	4.03
Fe_2O_3	2.51	2.52	2.55
t-CaO	62.61	63.01	63.13
f-CaO	.63	0.81	0.61
C-CaO	61.98	62.20	62.52
MgO	3.28	2.99	2.67
SO_3	2.77	3.41	3.21
Loss	0.89	1.58	1.04
Total	98.0	99.65	99.49
K_2O	0.57	0.56	0.54
SrO	0.04	0.04	0.04
TiO_2	0.22	0.20	0.17
P_2O_5	0.12	0.10	0.08
PbO	0.00	0.00	0.00
ZnO	0.01	0.01	0.01
Cu_2O	0.01	0.00	0.00
Mr_2O_3	0.02	0.03	0.06
L.R.	2.19	2.19	2.19
S.R.	3.21	3.19	3.39
A.R.	1.72	1.71	1.59
C_4AF	7.6	7.7	7.8
C_3A	7.1	7.2	6.4
C_3S	47.7	46.0	46.1
C_2S	26.1	27.1	28.9

Physical Test Results For Cements

Table 4

Test	1	2	3
Blaine	331	354	352
325 Mesh, passing	86.1	83.4	92.2
200 Mesh, passing	96.8	95.7	98.8
N.C.	23.2	22.5	23.2
Initial Set, Vicat	118	110	125
Expansion	0.25	0.18	0.14
Compressive Stengths	Mpa (psi)		
3 Day	19.3 (2797)	16.8 (2435)	20.2 (2928)
7 Day	25.6 (3710)	22.6 (3275)	25.7 (3725)
28 Day	32.9 (4768)	31.4 (4550)	34.1 (4992)

Particulate Emission Results Summary

Table 5

Date	Time	Location	Fuel	Clinker Production	Stack Temp °F.	% Moisture	Flow Rate ACFM	Grains ACF	lbs hr.	lbs/t Clinker
Apr 17/80	8:40 – 13:59	#2 Kiln Stack	20% RDF 80% Coal	151.57 (28.44 t/h)	394	13	160500	0.20	272	1.794
Apr 17/80	16:27 – 21:29	#2 Kiln Stack	20% RDF 80% Coal	123.00 (24.6 t/h)	381	17	135400	0.025	30	0.244
Apr 20/80	9:45 – 14:59	#2 Kiln Stack	20% RDF 80% Coal	140.66 (26.79 t/h)	401	21	160700	0.031	43	0.305
Apr 29/80	14:35– 22:34	#2 Kiln Stack	100% Coal	237.35 (29.35 t/h)	392	18	137700	0.024	29	0.1221
Apr 30/80	10:20 – 15:19	#2 Kiln Stack	100% Coal	150.02 (30.0 t/h)	393	20	139500	0.086	102	0.679
Mar 20/79		#1 Kiln Stack	100% Coal		384	22	167300		20	
Mar 21/79		#1 Kiln Stack	100% Coal		376	22	173308		19	

Daily Liter Weights and % Oxygen

Table 6

DATE	% Oxygen 24 hr Range	Liter Weights Shift 1	Shift 2	Shift 3
RDF AND COAL				
Apr 9/80	1.0 – 7.0	1515/1365	1340/1320	1380/1410
10	0.0 – 7.0	1490/	1380/1310	1340/1050
11	0.5 – 7.0	1250/	1570/	1120/1370
12	0.0 – 6.0	1630/1200	1270/1340	1170/1520
13	1.1 – 6.0	1340/1380	1470/1390	1160/1380
14	0.0 – 6.0	1390/	—	1080/1220
15	1.0 – 6.4	1310/	1270/	1130/1370
16	0.0 – 7.7	1340/1310	1450/1270	1305/1395
17	0.2 – 6.0	1470/1420	1230/1020	1240/1395
18	1.0 – 6.5	1440/1390	1360/1130	1365/1430
19	1.0 – 5.0	1360/1380	1360/	1320/1235
20	0.1 – 6.0	1280/	1320/1370	1200/1420
21	0.1 – 5.5	— /1280	1310/1070	1140/1000
22	1.0 – 7.0	1160/1560	1270/1390	1300/1455
23	0.7 – 5.0	1340/1280	1160/1080	1320/1330
24	0.7 – 4.5	1160/1150	1340/1340	1420/
25	1.0 – 5.0	1290/1310	1395/1320	1350/1360
COAL ONLY				
Apr 26	1.0 – 4.0	1080/1210	1330/1305	1330/1340
27	0.7 – 3.2	1280/1210	1205/1340	1360/1380
28	0.6 – 2.1	1320/1190	1325/1335	1360/1320
29	0.4 – 2.7	1200/1270	1000/1135	1290/1360
30	0.1 – 3.0	1330/1240	1330/1245	1300/1190
May 1	1.0 – 2.5	/1160	1190/1230	1310/

Stack Emissions Tests for SO_2 and NO_x

Table 7

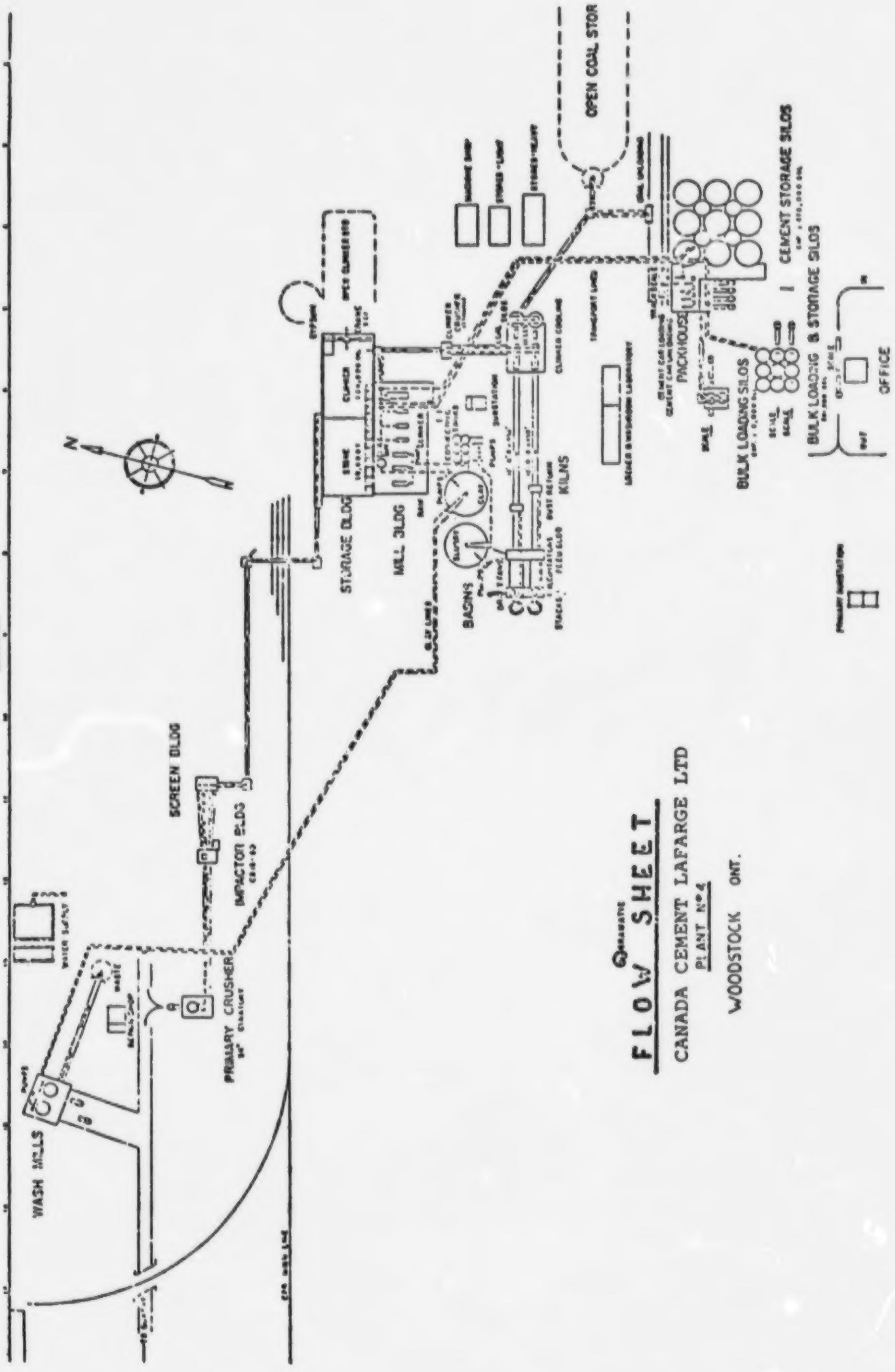
Date	Hours	SO_2 ppm	NO_x ppm
Apr 16/18	2:00- 3:00	393	290
Apr 17/80	9:40-10:40	467	196
	10:50-11:30	187	295
	11:40-12:30	64	303
	12:40- 1:50	364	234
	4:00- 4:50	76	108
	5:00- 5:50	36	159
	6:00- 7:10	8.0	50
Apr 18/80	9:00-10:10	5.67	79
	10:30-11:10	3.4	45
	11:20-12:10	1.4	17
	12:10- 1:20	1.1	6.9
	1:30- 4:10	1.0	5.5
	Base Line – Coal only		
Mar 20/79	13:55-18:05	2.72	—
Mar 21/79	12:50-15:30	3.49	142
Mar 22/79	11:25-14:35	99	102

Table 8

	Coal Ash %	RDF Ash %
SiO_2	38.5	59.0 – 60.5
Al_2O_3	20.1	7.6 – 7.1
Fe_2O_3	23.0	4.9 – 3.5
CaO	7.7	12.5 – 12.7
MgO	1.6	3.0 – 1.2
SO_3	5.4	1.6 – 0.8
Loss	1.12	4.5 – 0.9
K_2O	1.44	– 0.9
Na_2O	0.50	– 1.3
P_2O_5		– 0.6
TiO_2		– 1.4
ZnO		– 0.4
PbO		– 0.2
CuO		– 0.2
Other Elements (SrO, Mn_2O_3)		– 0.2

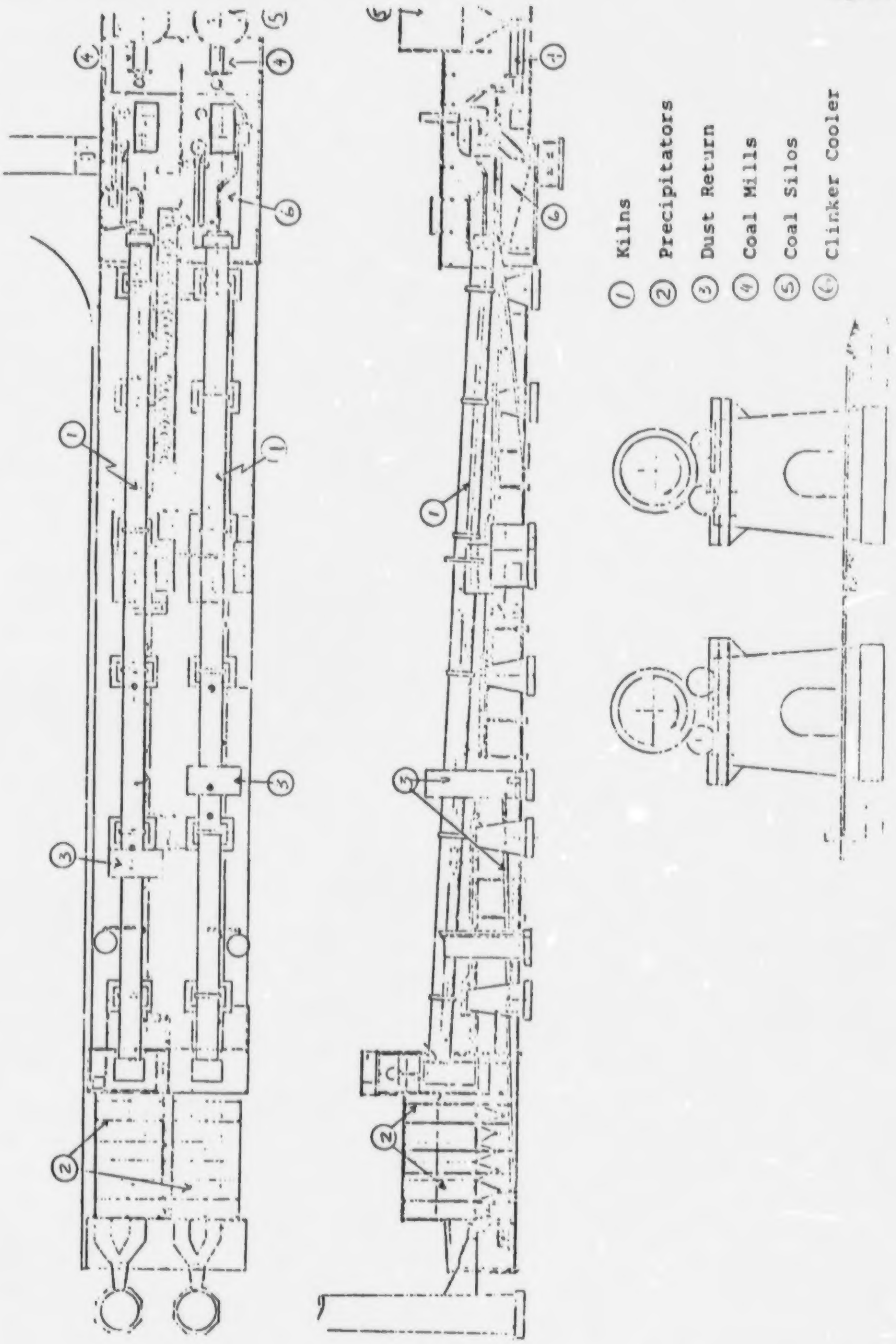
Diagramatic Flow Sheet 1967

figure 1



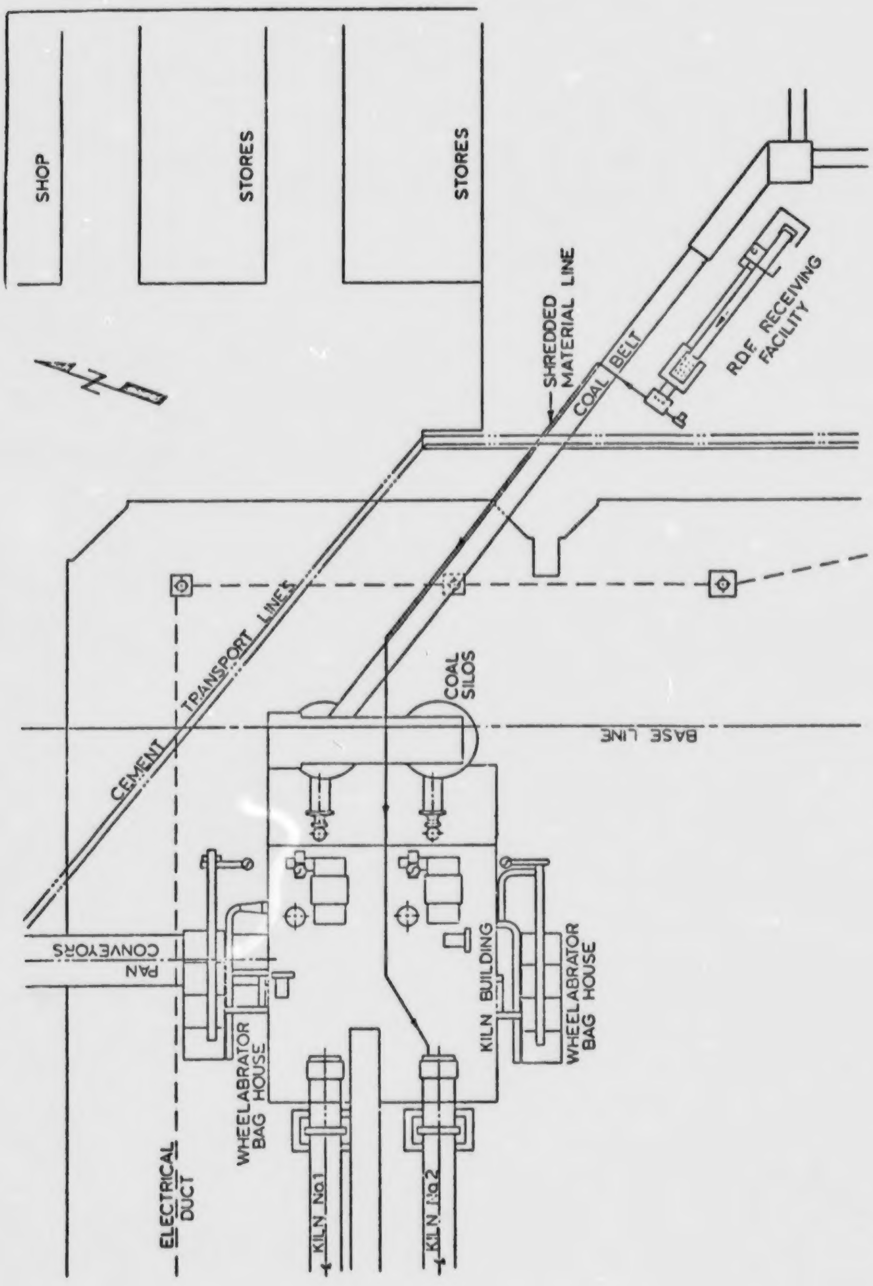
Canada Cement Lafarge Ltd.
Woodstock, Ontario

figure 2



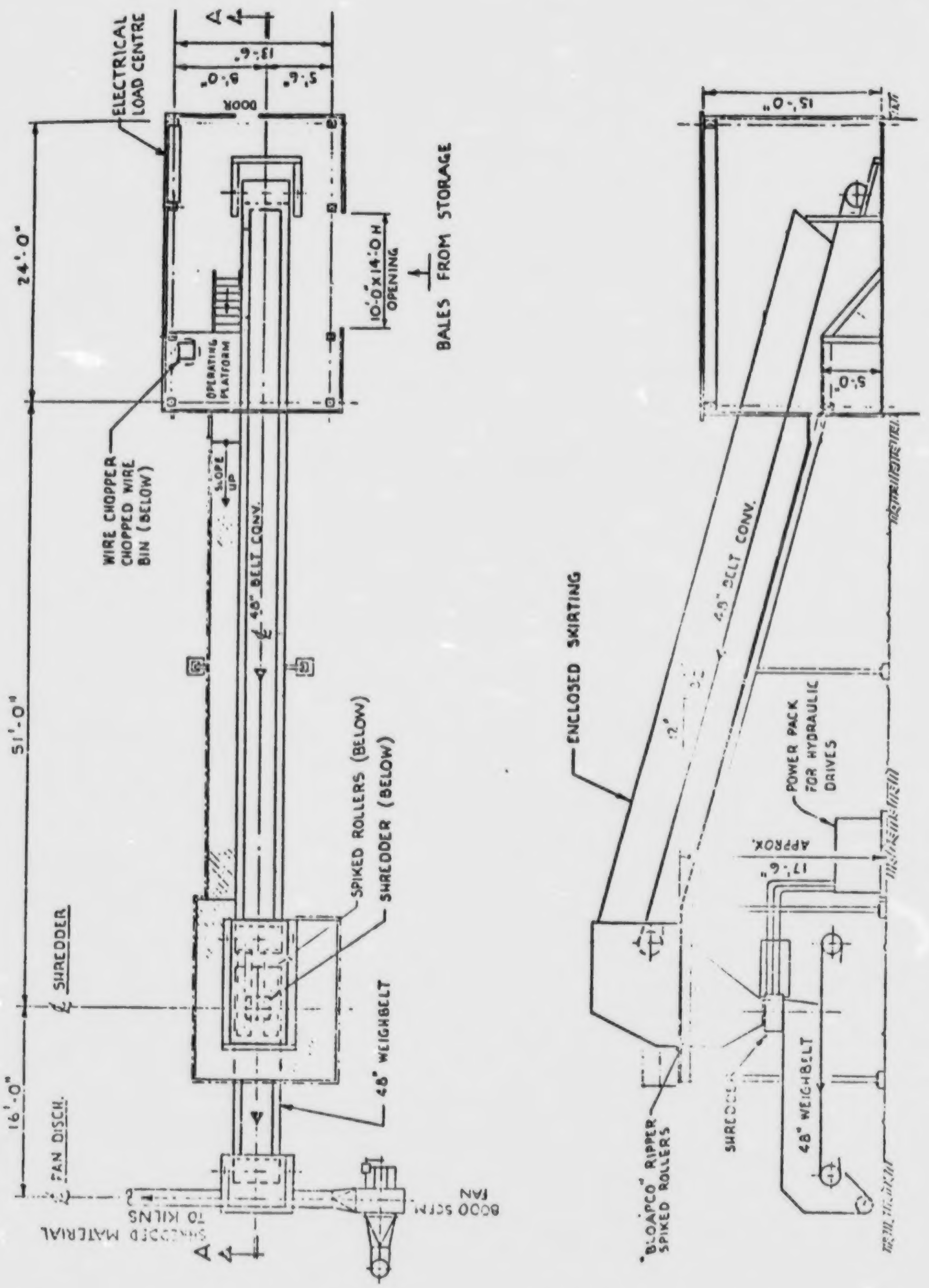
RDF Receiving Facility Site Layout

figure 3



RDF Facility

figure 4



The Use of RDF as a Burnout Fuel in Brickmaking

by:
Howard Penn
Brampton Brick Ltd.

and

E. E. Berry
E. E. Berry & Associates

Abstract

An examination was made of the feasibility of including a solid-fuel derived from municipal refuse as a burnout component in clay brick. It was found that up to 25 percent by volume (2.1 percent by weight) of the refuse derived fuel could be used without deleterious effects on laboratory prepared clay brick specimens. It was calculated that if all the heat available from the combustion of RDF at the 25 percent by volume replacement level was available during firing an energy saving of 1.43 GJ per 1000 brick could be achieved.

Executive Summary

An examination was made of the feasibility of including a solid-fuel derived from municipal waste (RDF) as a burnout component in clay brick manufacture. The literature was examined for previous work on burnout technology. It was found that many low-grade fuels have been suggested for this purpose, including lignite, sawdust, agricultural wastes and RDF. Patents have been filed in Holland with respect to some aspects of RDF use.

In the laboratory, employing the shale used by Brampton Brick Ltd., it was found that up to 25 percent by volume (2.1 percent by weight) of finely shredded RDF material, obtained from the Resource Recovery Centre, could be used without seriously affecting the quality of the fired products.

Theoretically, use of the finely shredded RDF fraction at the 25 percent (volume) level could provide a maximum energy saving of 1.43 GJ per 1000 brick (0.43 GJ per tonne). Ontario brick manufacturers produce approximately 1.1×10^6 tonnes of brick per year, most of which is produced in the four regional municipalities of Toronto, Peel, Halton and Hamilton – Wentworth. It was concluded that these areas could all be supplied with sufficient RDF material by one resource recovery unit processing about 120 to 150 tonnes per day of refuse.

Larger masses of RDF could be included in brick as burnout fuels if a material was developed of fine particle size but less fibrous in form. This would increase the energy savings and also the size of the market for RDF for this application.

Introduction

The manufacture of structural clay products, of which bricks are the major type, consumes a considerable amount of energy. In Ontario the primary fuel used is natural gas. On average, brickmaking in North America requires 2.3 GJ of fuel energy to fire one tonne of clay (equivalent to approximately 5.48 GJ/1000 brick).[1]

Ontario manufacturers produce more than 50 percent of the clay bricks used in Canada. In 1978, 365 million bricks, valued at approximately $45 million were consumed in Ontario, more than 90 percent being produced by Ontario brick plants.[2] The total clay products industry (which includes manufacturers of brick, tile and sewerpipe) in Ontario generated sales worth about $62 million, employed almost 1700 people and paid more than $21 million in wages and salaries.[3]

Bricks are manufactured at 7 plants in Ontario at the locations listed in Table A-1. Production is limited to three areas, the Niagara Escarpment, Metropolitan Toronto and to the east of Ottawa in Russell County. All these plants use Queenston or Georgian Bay shales as raw materials.[2,3]

According to Guillet,[2] the annual consumption of bricks in Ontario has been relatively constant over the past ten years. However, the share of the construction market taken by brick has declined. Future levels of demand have been estimated at an average annual growth of 3 percent in number of bricks consumed to the year 2000.[3] The future markets for sewer pipes and drain tiles are considered less certain due to competition from other materials.[2]

It is established practice in the manufacture of certain types of brick to blend an organic material (burnout) into the clay prior to firing. The included burnout material provides a portion of the fuel energy required for the firing process.

Municipal refuse is a potential source of organic fuel. At the Ministry of the Environment's Resource Recovery Centre, Downsview, Ontario, ***a refuse derived fuel (RDF)*** is prepared from urban garbage, The RDF from this source has a fuel value of approximately 19000 J.g.$^{-1}$ (dry basis). Preliminary examination of an RDF fraction suggested that this material might be suitable for use as a burnout fuel. This study has been concerned with evaluating the feasibility of the technical and economic aspects of using RDF as a burnout fuel in the manufacture of bricks and other structural clay products in Ontario.

This report is divided in two parts: Part I is concerned with the background to brickmaking and a review of the current state of the art of burnout technology with particular regard to municipal waste as a potential fuel source; Part II is concerned with the results of an experimental evaluation of a fuel derived from municipal waste for use as a burnout material and the discussion of the findings of this study.

Part I – Brickmaking and Burnout Technology

Brickmaking Processes

There are several processes by which bricks are made, depending to some extent on the materials being used and the age and size of the plant. However, for the purposes of general discussion, all processes may be reduced to a sequence of six fundamental steps (see Figure B-1)

1. **Excavation of clay or shale** is done by open cut quarrying or mining.
2. **Crushing and grinding.** Shales are crushed in jaw or roll crushers, raw clays are granulated. Grinding follows in either wet or dry pans, which coupled with screening, reduces the material to the predetermined particle size distribution necessary for optimum plasticity.
3. **Pugging.** Clay or shale and water are intimately blended to a paste consistency in a pug mill.
4. **Forming.** One of the following three processes is used to shape the clay body into brick form:- (a) *Soft mud process;* used for clays that are too wet or plastic to be passed through a die. The plastic clay (25% water) is fed to a gang mold, pressed, struck off and the molded product passed to a pallet. (b) ***Stiff mud process;*** clay (15 to 23% moisture) is subjected to a partial vacuum to remove entrapped air, and then extruded through a die to form a bar. The bar is cut to brick-size by a gang wire cutter. The process is favourable for high-speed automation and since less water is used it is more energy efficient than the soft-mud process. (c) ***Dry-Press process;*** clays containing 6 to 8% moisture are mold-pressed into individual brick-sized units.
5. **Drying** is one of the most critical stages in the brickmaking process since under poor drying conditions distortion, warpage, cracking and scum formation may occur. Periodic or tunnel driers are used at temperatures of 150 to 230°C. Waste heat from the cooling zones of the firing kiln is frequently used for drying. The dried brick contains about 1% moisture.
6. **Firing.** Brick kilns are either of the periodic or the continuous types. Continuous kilns, which are the more economical and more widely used, are in the form of a straight tunnel from 90 to 200 meters long. The brick is stacked onto cars that slowly carry it through the kiln. The kiln comprises a furnace zone, fired with oil, gas or solid fuel, where bricks reach (and soak at) a maturing temperature. A cooling zone follows, where annealing of the fired ware takes place. The temperature required and the time that bricks reside in the various kiln zones depends upon clay properties, the nature of any additions used and the desired final properties of the finished brick.

The physical and chemical changes that occur within the clay body during firing are complex. A sequence of distinct processes may be identified as temperature is increased, these are as follows:

1. Removal of residual absorbed water;
2. Dehydration, removal of chemically bonded water;
3. Oxidation of carbon present in the clay or formed during burnout of organics occurs. Iron is oxidized and traces of volatile inorganic compounds are also removed at this stage;
4. Incipient vitrification, involving melting of fluxes and softening of clay and the establishment of structural bonds occurs as the final step.

The durability of facing brick refers to its resistance to the agents of weathering – principally rainfall and freezing temperatures, as well as exposure to soluble salts such as sodium chloride from sea water and sulphates from industrial air pollution.

The characteristics of clay products that determine their durability on exposure to moisture and freezing temperatures are the phases present in the fired product, elasticity, strength and porosity.

Of these, porosity seems to be the predominant factor because, in most cases, when the pore structure is right for resistance to freezing cycles, stable phases and sufficient strength will also have been developed by proper firing.

The types and amounts of porosity in a clay body with satisfactory resistance to frost action are quite complex. The key seems to be related to the number of pores and how they are connected by finer capillaries. Across all types of fired clay materials, total porosity does not appear to be a factor, but in any specific material there is relation between total open porosity and resistance to the freezing of pore water.

Burnout Fuels in Brickmaking

History

Organic materials, deliberately or accidentally included in clay body material, are burned out on firing, leaving behind closed cavities within the fired ware. The resulting ware are of lighter weight than would be the case in the absence of the organic material and have good thermal insulation properties. In addition to their influence on the physical properties of the fired brick, organic burnout agents contribute to the energy required in the firing process.

Reports of research or patented processes of burnout components include: coal, sawdust, wood flour and bark, cornstarch, sunflower hulls, straw, natural organic fibers, potato and apple waste, dewatered sewage sludge, polystyrene beads, coke breeze, coal slurry, and fly ash.

The Technology of Burnout Fuels

Two practical objectives are achieved by the use of organic burnout components in brickmaking: (a) the production of a lightweight, thermally insulating brick, (b) reduction in the external fuel consumed in the kiln.

Under normal circumstances, the presence of even small amounts of carbonaceous material in the clay can cause problems in firing brick. Bloating may occur or distortion may be observed. To avoid these problems, changes in material composition of the body and the firing procedure may be required. Low density brick may be of low strength and exhibit high absorption. The ability of the market to consume such products will vary. In general they will be used as back-up rather than facing or structural brick.

In spite of these disadvantages, the potential fuel savings make consideration of the use of burnout fuels very attractive. It is generally estimated[1] that 2.3 GJ of energy are required to fire one tonne of clay (2300 KJ/kg) in a modern tunnel kiln. Table A-2 shows the fuel characteristics of three potential classes of burnout materials: coals; woodwaste; RDF

In practice it is not possible to recover all the potentially available fuel value. The major factors affecting the thermal efficiency of burnout fuel utilization are fuel density, ignition temperature, volatiles ash and moisture and ease of combustion.

Fuel Density

Burnout fuel replaces clay by volume in a unit of predetermined dimensions such as brick. It is this factor which leads to the production of lightweight ware on firing burnout-clay bodies. However, because clay has a specific gravity of about 2.0, the weight of burnout fuel that can be added may be limited by its specific gravity. With any clay mix there will be a maximum volume of non-plastic material that can be added beyond which the mixture ceases to be extrudable. Table 2 shows the Relative Bulk Replacement Factor (RBRF) of some potential burnout fuels.

Ignition Temperature

Organic burnout fuels do not ignite at room temperature. It is necessary to heat these materials to some elevated temperature (the ignition temperature) before they will start to burn and sustain their combustion. The ignition temperature is characteristic for the particular substance under consideration. Table 2 shows typical ignition temperatures for the fuels being considered in this report.

To achieve the ignition temperature means that there is a dead zone in the first few car lengths of a tunnel kiln in which no heat is liberated from the burnout fuel. This dead zone will require heat from some other source.

Volatiles

All fuels contain components that may distill off as smoke and gas and be discharged from the stack without combusting; thus causing a loss of some heating value. Both Robinson[1] and Murray and Liversage[5] suggest that the "wood-fire" odour, smoke or loss of combustion volatiles could be controlled by recirculating the evolved gas through burners or into the combustion zone where their thermal energy would be used.

In addition to their contribution to the possible loss of fuel values, volatiles may present an explosion hazard unless specific precautions are taken.

Ash and Moisture

Both ash and water in burnout fuels are causes of reduction in heat value. Both displace combustible material. Additionally, since water vapour must be evaporated and then heated to the gas temperature, moisture in the fuel actively contributes to energy wastage. It is estimated that approximately 2800 KJ are required to evaporate 1 kg of water and increase the vapour temperature to a stack exhaust temperature of 200°C.

Ease of Combustion

Some materials sustain combustion easily once their ignition temperature has been reached, others burn only with difficulty. The rate of combustion is largely determined by the availability of oxygen from the kiln atmosphere to the burnout fuel.

Part II – Evaluation of RDF as a Burnout Fuel

Experimental Examination of RDF as a Burnout Fuel

Materials

The principal raw material used for brickmaking at the Brampton Brick Plant (and elsewhere in Ontario) is a shale of the Queenston formation. Details of the geology, composition and ceramic properties of this shale are presented in Appendices A-3 to A-6.

The Ministry of the Environment's Ontario Centre for Resource Recovery produces a number of organic fractions derived from municipal waste, each with different physical and thermal characteristics. The material used in the present investigation was a finely shredded RDF fraction, details of the physical and chemical properties of which are given in appendices A-7 and A-8.

Experimental Methods

The experimentation employed comprised the following:

Materials Evaluation

a) Routine quality control tests of the shale source.
b) Analysis of the finely shredded RDF fraction.
c) Determination of relative bulk densities of shale and RDF.

Tests on Plastic Clay/RDF Mixes (Unfired)

a) Measurement of water-of-plasticity.
b) Measurement of drying-shrinkage.
c) Measurement of loss on ignition at 900°C.
d) Thermal measurements comprising: Differential Thermal Analysis (DTA), Thermal Gradient Firing (TGF), Thermal Dilatometric Analysis (TDA), and Carbon Burnout.

Evaluation of Fired Products

a) Water absorption.
b) Bulk density.

Preparation of Specimens

After some preliminary mixing trials the formulations shown in Table A-9 were prepared as follows. The preweighed dry components (RDF and shale) were tempered with water in a small scale laboratory shaft mill (pug mill). The amount of water added was determined by visual and manual inspection of the mix until a homogeneous material that could be handformed was obtained. This being the standard approach to formulation in the industry. The total quantity of free water (water-of-plasticity) in the mix was determined from the difference between green- and dry-weights.

Each test batch was extruded and vacuum deaired in a laboratory extruder to form bars 3.8 x 3.8 x 15.25 cm. (1.5 x 1.5 x 6 inches). Approximately 40 bars were made from each batch. Each bar was numbered and marked for shrinkage determination. The green weight of each was determined. Five bars from each batch were shipped to Harrop Laboratories for thermal analysis. The remaining bars were dried at 140°C for 12 hours.

Test bars were fired in a laboratory kiln on a 12 hour cycle, illustrated schematically in Figure B-2.

Experimental Results

Measurements made on the test batches were of three types:

a) measurements of green bars;
b) visual evaluation of green bars;
c) measurements on fired bars;
d) visual evaluation of fired bars;
e) thermal analysis on green materials;
f) visual evaluation of fired materials from thermal analysis

Evaluation of Green Test Bars

Certain technically important factors are not readily quantified and reliance is placed in the industry on experienced, subjective evaluation of test bars. With respect to the present work, it was noted that for batches containing more than 25 percent RDF by volume, the plastic mixture was difficult to form, had low apparent green strength and did not cut to give dimensionally acceptable bars. Surface texture was also deleteriously affected by inclusion of RDF.

Evaluation of Fired Test Bars

The quality of fired brick from a known source of shale can be estimated readily from measurements of firing shrinkage, water absorption and bulk density. These tests were applied to the fired bars, the results are summarized in Table A-10.

Thermal Analysis of Test Batches

The following thermal analysis procedures on test bars were performed:

a) Thermal Gradient Firing (TGF)
b) Differential Thermal Analysis (DTA)
c) Thermal Dilatometric Analysis (TDA)
d) Carbon Burnout Tests

From the TGF analyses it was concluded that the firing range for all batches (0 to 30 vol.% RDF) was 1930 to 1990°F (1054 to 1088°C). Although no change in firing range was observed, the bars with RDF were noted to be more porous than the control bars (see Table A-11).

The data from DTA showed that burnout of the RDF was essentially completed in the temperature range 250 to 560°C. No significant differences in DTA thermograms were noted over the range of RDF replacement studies and no reactions, other than burnout, were observed that might have indicated significant changes to the brick-forming reaction sequence caused by the use of RDF.

Similarly, in the data from TDA no significant influence on dimensional changes during firing was attributable to the use of RDF.

Carbon burnout tests showed that RDF burnout was complete at the lowest temperature examined (538°C) which is in complete agreement with the interpretation of the DTA results noted above. The burnout was probably aided by the open pore structure of the formed bars.

Discussion

Technical Aspects of RDF Utilization

As was discussed earlier, from the technical standpoint, for a burnout fuel to be usable in brickmaking, it must be possible to blend the fuel with the shale/water mix in such a way that the following criteria are satisfied.

a) It should be possible to obtain a homogeneous mix without increasing the energy required for mixing or the mixing time. Preferably mixing should be effective in the same unmodified equipment used for routine brick production.

b) The water of plasticity should not increase excessively, since this water requires heat for its removal in the dryer.

c) The plastic mix must retain its shape after forming and it must be possible to cut the continuous, formed bar with the usual wire-cutter equipment without excessive wire breakage or the formation of badly cut end surfaces on the green brick unit. Large particulate or fibrous body inclusions or excess non-plastic material effects all of these criteria.

Table 4 shows a summary of the data obtained on the properties of the plastic mixtures. Consider firstly ***water of plasticity,*** it is clear from Table 4 that as the addition of RDF was increased, the mixes required more water to retain the desired plasticity. This is to be expected since RDF is a non-plastic material. However, the required increase in water content will have an influence on the practical energy value obtainable from the RDF.

With respect to other properties associated with the unfired (green) brick, the upper limit of inclusion of RDF in the form supplied was 25% by volume (2.11 percent by weight). Addition of RDF at more than this level resulted in poor green-strength and problems associated with forming and cutting brick units (see Figure 3).

Water absorption of the fired brick was adversely affected by the inclusion of RDF. The maximum permissible absorption, 22 percent, was exceeded for the samples containing 30 percent RDF by volume (2.65% by weight). Increasing the temperature of firing had little effect on water absorption.

Shrinkage after firing was not significantly affected by RDF additions, increased drying shrinkage being largely compensated by reduced firing shrinkage as the amount of RDF used was increased.

Thus from the technical viewpoint it would appear that up to 25 percent of finely shredded RDF can be added to Brampton Brick Ltd. shale mix to make bricks of reduced weight with adequate properties for use in construction. Use of RDF in this way will contribute to a saving of both energy and materials.

The RDF used was found to have a fuel value of approximately 19000 $J.g^{-1}$ (on a dry basis). It burned out completely with no indication of black coring. The resulting fired brick test pieces were of a lightweight type, the bulk density being lower as the amount of RDF included in the mix was increased.

Conclusions

1 From the technical point of view, the present work has shown that up to 25 percent by volume (2.1 percent by weight) of finely shredded RDF can be included as a burnout fuel in brickmaking without seriously affecting the performance of the resulting brick.

At the 25 percent by volume replacement level, the results from the laboratory investigation indicate that the following benefits should be attainable from the use of RDF as a burnout fuel:

a) Fuel savings in the kiln
b) Some saving of materials
c) Reduction in unit weight of the finished product
d) Improved insulating properties of the finished product

2 Used at the maximum level of replacement, the maximum estimated heat savings are approximately 1.43 GJ per 1000 brick produced. Actual savings cannot be estimated until a complete energy balance is made on a producing kiln system. On the basis of the data available from the present work, and at 1980 energy prices, it is estimated that cost savings could be expected in the range of $20 to $30 per tonne of RDF used.

3 The amount of RDF material that can be used is largely limited by particle shape which affects the water of plasticity, forming properties and absorption of the finished product. A fuel with less fibrous and more spherical particulate components would be expected to be usable in larger quantities in brick.

4 A single supply, located in Halton or Peel, of 60 to 70 tonnes per day of finely shredded RDF would serve the brick industry in Southern Ontario. A larger source would be required if more material can be introduced through development of RDF with a more suitable particle shape.

References

1 Robinson, G.C.; "How to use burnout as a replacement fuel" **Paper presented at the Plant Forum, Mississippi and Louisiana Brick & Tile Assoc.**, Feb. 1977.

2 Guillet, G.R., Gartner Lee Associates Ltd., "Shale for brick-making and the clay products industry. Policy and strategy for Ontario". Report for **Ontario Ministry of Natural Resources** (1979)

3 Proctor & Redfern Ltd., "The clay brick industry and the shale resources of Ontario". Report for the **Clay Brick Association of Canada** (1978)

4 Isenhour, C.T., "Sawdust addition to a shale body". **Am. Ceram. Soc. Bull. 58** (12), 1197-98, (1979)

5 Murray, M.J. and Liversidge, R.M.; "The use of cubic shape sawdust in heavy clay products". **Ceramurgia International, 4** (3), 119-124 (1978)

6 Ger. Offen. 2,853,709 (1980)

7 Fr. Pat. 2,094,851 (1972)

8 U.S. Pat. 3,310,614 (1967)

9 Brit. Pat. 1,149,487 (1969)

10 Brit. Pat. 1,233,220 (1971)

11 Belg. Pat. 787,569 (1972)

12 Schweizer, G.; "Optimization of sludge dewatering and utilization of bark and sludge in brickmaking". **Wochenbl. Paperfabr. 103** (22), 833-9 (1975)

13 Neth. Appl. 77 11,341 (1978)

14 Neth. Appl. 77 06,797 (1978)

15 Riedel, R.; "Red mud as a raw material for bricks". **Aluminum 54** (10), 635-637, (1978)

16 Anon.; "Eirichs waste happening". **Tonind. -Ztg. Fachber 102** (1), 30-39, (1978)

17 Spanish Pat. 443,826 (1977)

18 Boesmans, B., Colon, F.J. and van der Velden, J.H.; "Bricks manufactured from clay and municipal refuse". **2nd Recycling World Congress,** Manila (1979)

19 Colon, F.J. and Boesmans, B.; "Applied industrial research work on the use of raw materials from municipal refuse". **Resource Recovery and Conservation 5.** (1980), 85-98

20 Bird and Hale Ltd.; "Municipal refuse statistics for Canadian Communities of over 100,000 (1976-1977)". **Report for Waste Management Branch, EPS. Environment Canada** (1978)

21 Ahlberg, N.R. and Boyko, B.I.; "Research and development facilities at the Ontario Centre for Resource Recovery". **Proc. 1978 Natl. Waste Processing Conf. ASME Solid Waste Processing Div.** (1978)

22 Brownell, W.E.; Structural Clay Products, **Springer-Verlag,** New York, 1976, 198-203

Appendix A Tables

Location, Production Capacity and Estimated Fuel Usage of Ontario Brick Manufacturers

Table A-1

Company	Location Municipality	Region	Annual Production Capacity (tonnes)	(bricks x 10^6)	Estimated Fuel Usage (GJ/yr)
Brampton Brick Co.	Brampton	Peel	180,000	72	414,000
Canada Brick Co.	Streetsville	Peel	335,000	134	770,500
	Burlington	Halton	212,000	85	487,600
Domtar Ltd.	Cooksville	Peel	125,000	50	287,500
	Ottawa	Ottawa-Carleton	125,000	50	287,500
Toronto Brick Co.	Toronto	Toronto	100,000	40	230,000
Hamilton Brick Co.	Hamilton	Hamilton-Wentworth	30,000	12	69,000
			Totals:	443 x 10^6	2,545,600

Fuel Characteristics of Potential Burnout Additives

Table A-2

Additive	% Water	% Volatiles	% Ash	(KJ/kg) Hhv	RBRF*	(°C) Ignition Temp.
Coal: Bituminous	2-3	25	6	35,500	1 to 1.2	410
Lignite	35-40	28	6	17,300	1 to 1.2	–
Anthracite	4-5	5-6	10	33,100		590
Woodwaste	20	85	1	20,000	0.6	310 – 370
RDF	7.5	74.7	15.0	18,967	0.08	270 – 300

NOTE: RBRF is the Relative Bulk Replacement Factor, it is defined as:

$$\frac{\text{mass (kg) of Burnout fuel}}{\text{volume (m}^3\text{) of shale (or clay) replaced}}$$

Shale

The shale used at Brampton Brick Ltd. comes from a source in the Queenston formation. The Queenston formation is an upper Ordovician shale, characteristically brick-red in colour, thick bedded and moderately soft. It is widely used as a source of material by the heavy-clay products industry in Ontario.

Queenston shale is remarkably uniform in both chemical and mineralogical composition, lime being the most variable component (range 3 to 18 percent). The average chemical and mineralogical compositions of Queenston shale in the Toronto-Hamilton area are given in Table A-4 and A-5 respectively.

Measured properties of the shale used in the present work are given in Table A-5.

Refuse Derived Fuel (RDF)

Approximately 45 kg. of RDF was supplied from the Ontario Ministry of the Environment, Resource Recovery Centre. This plant is a production-size, research and development facility. A full description of the resource recovery procedures has been presented by Ahlberg and Boyko.[5] Figure B-1 shows a schematic representation of the recovery process as it affects production of the RDF used in the present work. Air classified, light fraction material leaving the plant at the indicated location in the production stream was further shredded to pass ⅜" screens.

Properties of the material were determined by the Ontario Ministry of the Environment and Ontario Research Foundation. These data are given in Tables A-6 and A-7.

Chemical Analysis – Queenston Shale Table A-4

	Average %
SiO_2	59.27
Al_2O_3	13.79
Fe_2O_3	6.29
CaO	7.60
MgO	2.83
Na_2O	2.59
K_2O	3.73
TiO_2	0.80
CO_2	7.29
H_2O+	2.73
H_2O-	0.80
Sulphide	0.02
Loss on Ignition	8.75
Soluble Sulphates	0.51
C	1.53

Mineral Analyses – Queenston Shale Table A-5

	Average %
Non-clay Minerals	
Quartz	26
Calcite	11
Dolomite	1.8
Soda-lime Feldspar	1.3
Clay Minerals	
Illite	A
Chlorite	B
Expanding minerals*	D

(A = Abundant; B = Moderate; D = Trace)
*Note: Vermiculite

Analysis and Properties of Brampton Brick Shale Table A-6

Component	Weight Percentage
Calcium carbonate	10.0
Soluble SO_4^{2-}	0.04
Clay Minerals	29.8
Moisture (as mined)	4.2

Average Screen Analysis

Screen Mesh	Percent Retained
8	0
10	2.6
20	29.8
50	60.5
100	72.8

Calculated Fineness Modules = 1.66 ± 0.17

Properties of RDF Fraction Used In Experiments* Table A-7

i) Bulk Density	100 kg/m³
ii) Moisture	5.9 %
iii) Ash Content	12.8 %
iv) Calorific Value	18,967 joules/gm
v) Volatile Matter	74.7 %
vi) Ash Fusion Temperature	1160 °C
vii) Component Analysis	
Paper	57.4 %
Natural Organics	3.6 %
Synthetic Organics	9.5 %
Ferrous Metals	0.2 %
Non Ferrous Metals	0.2 %
Glass	0.0 %
Unseparated Fines	28.6 %

*Note: Data supplied by OME.

Data from Semi Quantitative X.R.F. Examination of Ash from Finely Shredded RDF Table A-8

A search was made for all elements with atomic number greater than 8. Approximate values (weight %) are given below for all elements detected. Elements with a blank entry and elements not listed were not detected in the sample.

11 Sodium	2.4	28 Nickel	0.04
12 Magnesium	1.4	29 Copper	0.30
13 Aluminum	5	30 Zinc	0.31
14 Silicon	13	33 Arsenic	—
15 Phosphorus	0.27	35 Bromine	TRACE
16 Sulphur	1.2	38 Strontium	0.02
17 Chlorine	0.66	40 Zirconium	0.02
19 Potassium	0.84	41 Niobium	—
20 Calcium	10	42 Molybdenum	—
22 Titanium	1.2	47 Silver	0.01
23 Vanadium	—	50 Tin	0.01
24 Chromium	0.09	51 Antimony	0.02
25 Manganese	0.14	56 Barium	0.1
26 Iron	1.9	74 Tungsten	—
27 Cobalt	—	82 Lead	0.26
		39 Yttrium	TRACE
		48 Cadmium	0.01

Relative Proportions of Shale and RDF Used for Forming Test Bars

Table A-9

Batch No.	% RDF by volume	Proportions of Dry Components (by weight) % RDF	Proportions of Dry Components (by weight) % Shale	Water of Plasticity as % of Green Wht.	Calculated Composition (% by weight) RDF	Calculated Composition (% by weight) Shale	Calculated Composition (% by weight) Water
1	0	0	100	12.96	0	87.04	12.96
2	10	0.86	99.14	14.00	0.74	85.26	14.00
3	15	1.36	98.64	14.50	1.16	84.34	14.50
4	20	1.91	98.10	15.99	1.60	82.41	15.99
5	25	2.53	97.47	16.57	2.11	81.32	16.57
6	30	3.22	96.78	17.60	2.65	79.75	17.60
7	40	4.92	95.07	19.60	3.96	76.44	19.60

Properties of Laboratory Fired Bars

Table A-10

Batch No.	% RDF by volume	Firing Shrinkage %	Firing Shrinkage Change vs. control (%)	Total Shrinkage* %	Total Shrinkage* Change vs. control (%)	Water Absorption %	Water Absorption Increase over control (%)	Bulk Density kg/m^3	Bulk Density lb/ft^3
(control) 1	0	1.35	0	3.85	0	15.27	0	1802	112.5
2	10	1.25	−7.4	3.82	−0.80	18.15	18.86	1776	110.9
3	15	1.19	−11.9	3.83	−0.78	19.15	25.41	1760	109.9
4	20	1.18	−12.6	3.83	−0.78	19.48	27.57	1705	106.5
5	25	1.23	−8.9	3.83	−0.78	20.95	37.20	1690	105.5
6	30	1.03	−23.7	3.83	−0.78	23.16	51.67	1674	104.5
7	40	1.01	−25.2	3.81	−1.04	27.33	78.98	1541	96.2

Notes: *Total Shrinkage = Dry Shrinkage (from Table 4) + Firing Shrinkage

Water Absorption Data from Test Bars Subjected to Thermal Gradient Firing

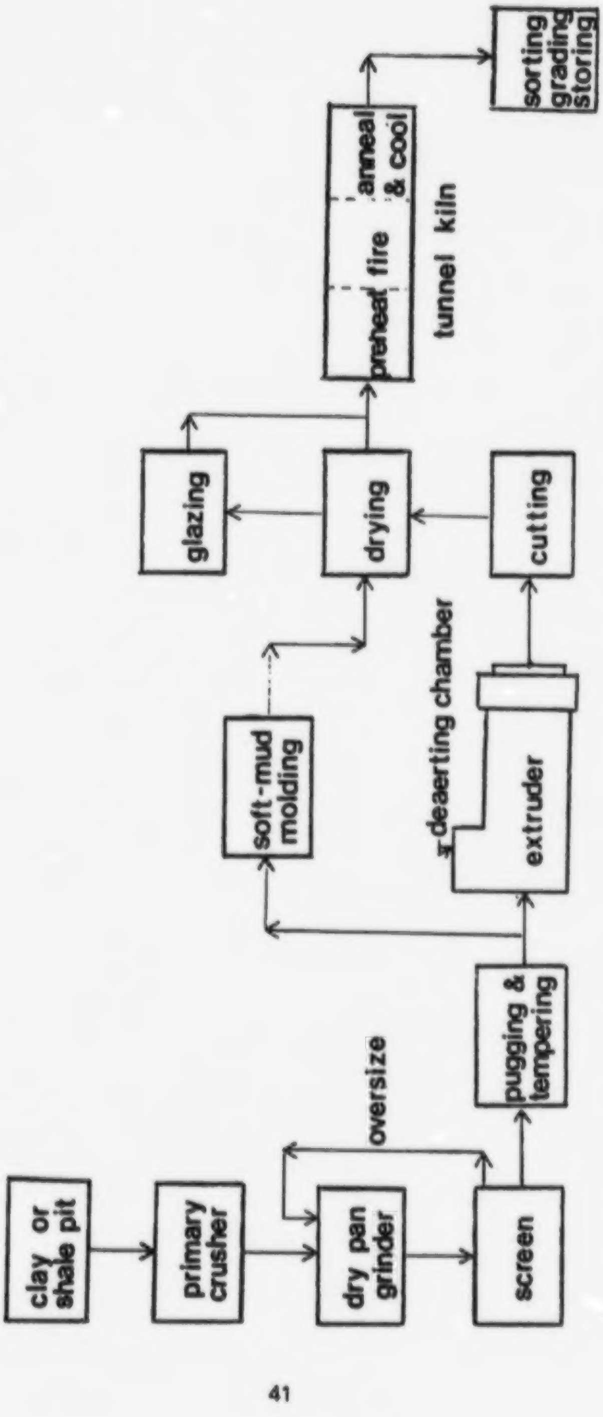
Table A-11

Sample	Temp. Range/Mean °C	% Absorption
Control	1060 – 1078 1069	13.77
	1078 – 1092 1085	12.89
10% RDF	1060 – 1078 1069	14.42
	1078 – 1092 1085	13.19
15% RDF	1058 – 1078 1068	16.42
	1078 – 1095 1087	15.57
20% RDF	1058 – 1078 1068	17.41
	1078 – 1094 1086	16.39
25% RDF	1056 – 1030 1068	18.25
	1080 – 1097 1088	17.16
30% RDF	1058 – 1080 1069	21.96
	1080 – 1094 1087	20.25

Appendix B Figures

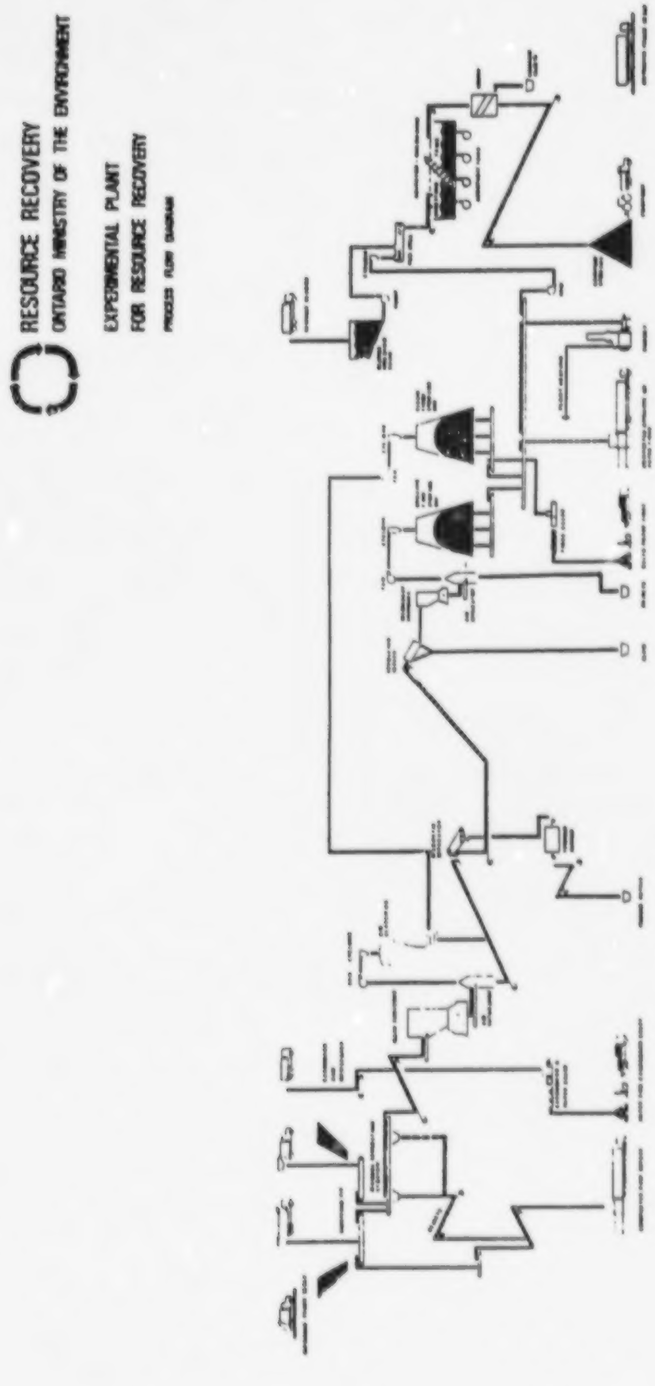
The Brick Manufacturing Process

figure B-1



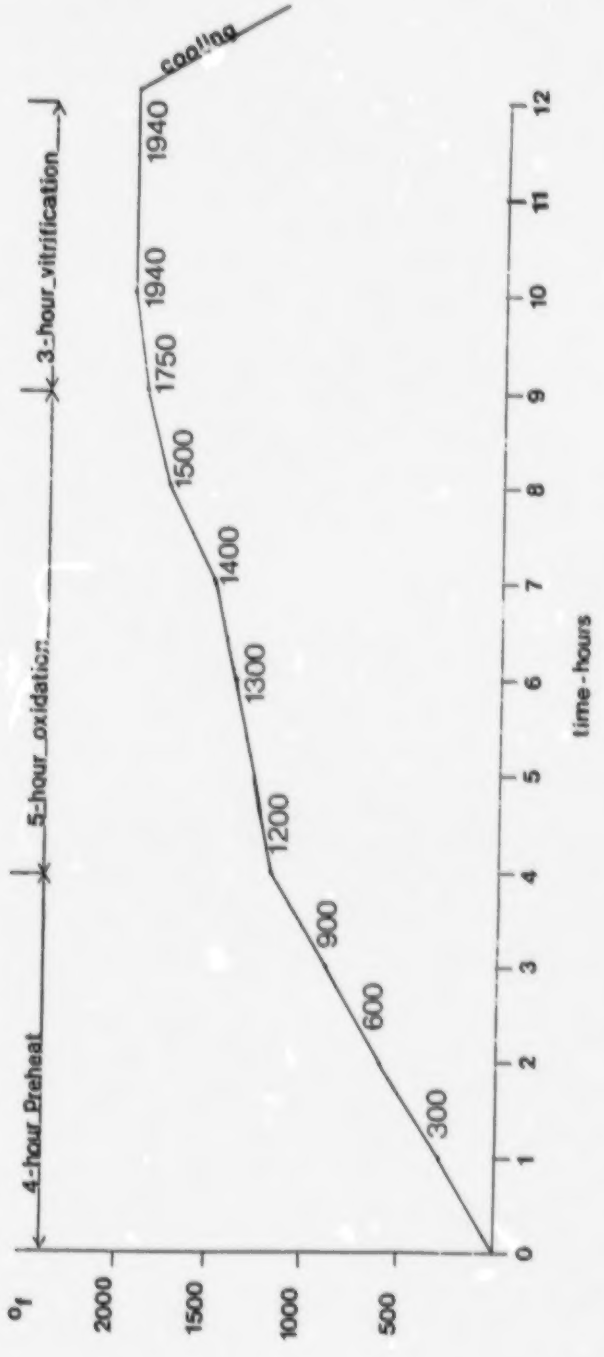
Experimental Plant for Resource Recovery Process Flow Diagram

figure B-2



12 Hour Firing Curve

figure B-3



Ames Solid Waste to Energy System 1975 – 1982

by:
Arnold O. Chantland
Public Works Director City of Ames
526 Main Street, Ames, Iowa 50010

Abstract

The need for a land conserving, solid waste disposal system and the desire for a low sulfur boiler fuel, were major factors enticing the Ames, Iowa, community to proceed with materials recovery from Solid Waste.

Seven years of operation have allowed the City to restrict land use to about one acre of land per year to serve a county population of approximately 72,000. A six year accumulated record shows the separation has produced over 13,000 tons of ferrous metal and 180,000 tons of boiler fuel. This pioneering effort has provided many insights on how to process and handle materials produced from the community's waste.

Introduction

In 1971, the Iowa Legislature placed all subdivisions of the State of Iowa on notice that environmentally acceptable solid waste disposal systems must be in effect by July, 1975. This action prompted county and city governments to investigate combined facilities for handling the disposal of solid waste on a county wide basis. Since most of the County's population and thus most of the waste was concentrated in or near the Ames area, the City of Ames was asked to conduct an investigation of feasibility of a combined operation. During this investigation, the county and the smaller communities concluded that it was not practical to operate on an individual basis but that the various units of government should combine their efforts to share in the cost of a single operation. Under this operation the county government and other municipal governments in the county would agree to contract with the City of Ames to share in the landfill or other solid waste operations that may take place in the future.

Goals and Objectives

After considerable study and investigation, several goals and objectives were formed. These are:

1. The system would provide for the conservation of resources including both land and the reuse of materials from the throw-aways of our society.
2. The private collection system would not be changed; thus the system must accommodate both private and license haulers.
3. The system must provide a solid waste disposal system that would serve a county wide area for a period of twenty years.
4. The system is to provide a facility to produce a low-sulfur supplementary fuel to be used in the Ames Municipal Electric Plant.
5. This system should strive to achieve costs of operation similar to approved landfills for similar sized populations.

The Ames Operation

The Ames plant is designed primarily to separate usable materials from the waste stream by mechanical means. Initially, as the waste is received onto a large tipping floor, the materials are examined visually for any toxic or hazardous wastes. The extraction of these wastes are most important in this type of processing plant since they may result in employee injury, fires, or explosions. Additional items extracted either by hand or by the front-end loader, which is equipped with a four-in-one bucket, includes such things as large tires, mattresses, rolled rugs, and other materials containing spring wire such as seat cushions. Heavy ferrous metal is also extracted and placed into a large 40 cubic yard container for sale to a salvage dealer.

The tipping floor entrance provides for both large and small vehicles. Fees of $1.00 per pickup; 0.50 for smaller vehicles; and $3.00 for all trailers, or trucks over the scales are charged at the entrance. All trucks and other major carriers of refuse are directed over a scale, which automatically records the weight through the use of prepunched cards similar to a credit card. This system not only provides the city with the weight of each vehicle but also, through the use of master lists which automatically records the net weight, the type of material, and the hauler identification for billing purposes.

The waste materials on the tipping floor are moved from this area to a large Z-pan horizontal conveyor through the use of the front-end loader. This variable-speed conveyor determines the input to the shredding and screening system (see Figure No. 1). As the material moves through the primary shredder, it is reduced to a nominal size of about 7". At the outfeed of the shredder, the material is immediately subjected to a three-stage electromagnet which removes approximately 85% of the ferrous materials in the waste stream. Extracted ferrous metals amount to about 5% of the incoming wastes. The ferrous material is deposited on conveyors and delivered to a semi-trailer for transport to the market.

The remaining output from the primary shredder is conveyed over two rotary disc screens, with two resulting material sizes. The larger oversized material is delivered to the secondary shredder for further reduction in size. The bottoms from the first disc screen, which are approximately 1½" or less in size, are then sent to a second disc screen for further separation. The second disc screen is sized to extract the glass, dirt, and grit which is less than ⅜". This glass and grit, which comprise about 12%-14% of the total material, is then taken out of the system and landfilled. The oversized material, which now ranges from ⅜" to 1½", is joined with the material that has been fine ground to about the same size by the secondary shredder. The materials are then delivered to a surge bin prior to air classification.

The air classification process consists of feeding mechanisms to create a uniform feed into a turbulent air stream. The air stream separates the light material, which is the fuel fraction, from the more inert heavy fraction. The light fraction is delivered to a pneumatic conveying system, which transports the material about 700 feet to a storage bin for use by the electric power plant. The heavy fraction, which contains about 15% of the total ferrous material, is subjected to magnetic separation for additional ferrous removal. This ferrous material is then joined with the other ferrous extraction and sent to the transport trailer. The remainder of the heavy fraction is elevated to the top of the process area and then placed into either of two storage bins. The material is then hauled to the sanitary landfill. The rejects at this point represent approximately 10% – 12% of the incoming waste.

The original plant had a noncombustible separation system which consisted of a trommel screen and eddy-current separators. This subsystem has been discontinued because the Iowa bottle bill extracted most of the aluminum from the waste.

The refuse storage silo is located within 150′ of the electric generating facility. The electric generating plant, on command, extracts the prepared waste from the silo through the use of the Atlas System drags. These drags and conveyors drop material into pneumatic pipelines which deliver the material directly to the power plant boilers. The bin serves not only as a storage facility but as a metering device that is remotely controlled from the main control room of the power plant. The material is burned both in suspension and on grates as a supplement to the coal firing operation. This plant has two speader-stoker type boilers with traveling grates and two pulverized-coal type boilers with dumping grates. Feeding rates to the spreader-stoker type boilers are up to 50% by fuel value, and the feed rate on the pulverized coal boilers are up to 20% by fuel value.

Other Sub-Systems

Since the plant is a major effort towards conservation of resources, several other sub-system operations are handled as part of the process. First, anyone wishing to dispose of used oil may bring it to the plant in a separate container and this oil will be placed in a 10,000 gallon underground storage tank for later resale. This plant also accepts logs which are cut in lengths less than 6 feet. These are turned into wood chips through the use of a 4′ x 6′ box chipper. Wood chips are sold for mulch around nursery stock and may be used as large animal bedding. Although there is a demand for wood chips, very few logs are received due to the high demand for fireplace wood.

Another sub-system includes the ability to bale paper or cardboard. Bundled newsprint is accepted at the plant, and this material is resold as recycled paper or to companies processing materials for insulation. Box board may also be salvaged through separation and baled for resale to paper companies. Box board is separated only from commercial loads which contain a high percentage of the material and very little of other wastes. Marketing takes place during the upper level of the price cycle; otherwise the material is processed for fuel.

Large ferrous containers or appliances which are not desirable for shredding, are extracted from the wastes and placed in a large container. This rough ferrous material is then sold to a local salvage company.

Problems and Solutions

Some major problems were encountered during the shake-down phase of the first 2-3 years of operation. The following are brief descriptions of each problem and modification accomplished.

Problem: Excessive combustible ash at pulverized coal boiler.

Solution: Bottom grates with a dumping capability were added to the pulverized coal suspension-fired boiler unit. This was necessary to enable complete burning of the RDF because it was found that large particles and those with relatively long combustion times (cardboard, wood, etc.) require a longer combustion retention time. The new 65 megawatt pulverized coal boiler is also equipped with dumping grates.

Problem: Excessive wear and non-combustible ash at boilers.

Solution: A solution was urgently needed that would reduce the excessive erosion/wear that was taking place in pipelines and nearly every piece of eqipment beyond the primary shredder. In a short two (2) years, all of the pipeline between the plant and the storage bin, most of the wear backs on the pipelines and most of the airlock feeders had already been replaced. The ash was approximately 20% which meant more ash handling and slagging for the electric utility. The solution decided upon for this problem was installation of two (2) disc screens (see Figures 2 & 3). The first disc screen would perform the function of dividing the product into two (2) streams where only the oversized material would be sent to the second stage shredder; thus, reducing the wear and power requirements for the No. 2 mill. The second stream of finer material is then run through the 2nd disc screen where the fines are extracted and delivered to the reject bins. These fines are the material we are most anxious to get rid of. Since the installation of these screens, we have not replaced any of the pipelines in over three (3) years, the ash content of the product has been cut in half and the wear on all components has been reduced.

Problem: Excessive dust in the process area.

Solution: Excessive dust from shredders, the air classifier and from the operation created major cleanup problems, fire hazards and required personnel to wear masks during the processing shift. This problem was attacked by the installation of the baghouse dust filter with appropriate dust pick-up points. The discharge from the air classifier also is sent to the baghouse for cleanup. Recent tests for dust levels by an independent testing laboratory, indicated that all points in the plant now meet the minimum requirements with the exception of one small area at the discharge of the No. 2 Shredder.

Problem: Storage bin operating problems and excess cold air to boilers.

Solution: The operating infeed conveyors in the RDF storage bin were combined from four into two with the addition of a pair of cross-feed screw conveyors. These added conveyors enable four infeed conveyors to be used to feed two RDF boiler feed systems and thus reduce air to the boilers. Prior to this change, only two infeed conveyors were sometimes used, resulting in operating the sweep bucket system at relatively high speeds for the RDF retrieval; this was felt to be one of the contributing factors to rapid storage bin floor wear.

Problem: Material wrapping around scalping roller.

Solution: The air classifier mechanism requires that a uniform feed of material must enter this piece of equipment. A scalping roller is used to level the material feed and would hold up the operations due to excessive amount of strip materials such as paper tapes, magnetic tapes, or rags. This problem was solved by the manufacturer who designed a v-notch scalper that has reduced the wrapping problem to routine maintenance.

Problem: Bridging in the surge bin.

Solution: Although the surge bin is 7 feet across between two vertical walls and has a back wall which has about 4 to 1 slope, this bin would bridge from side to side and would require considerable time and effort to break up the bridging. This problem was solved by an air cannon that was installed near the bottom of the surge bin. A few blasts of air from the cannon will now quickly correct this problem.

Problem: Bridging and jamming at transfer points.

Solution: One of the most common stoppages associated with the production of this type of material is the bridging and jamming at transfer points. This problem was reduced or eliminated by the reduction in any funneling action at these transfer points. This material simply cannot be funnelled onto smaller conveyors or even into the center of a conveyor.

Problem: Dribbling from belts at transfer points.

Solution: The receiving area of the transfer belts typically have rubber belted shielded sides to prevent the material from overflowing the belts. However, typical material transfer belts are equipped with a set of rollers set closer together than normal and at varying angles from the flat tail pulley to the final configuration of the transfer belt. These pulleys permit dips in the belt and small slots occur along the shields where this feathery material finds its way off the belt and into the process room. This problem was substantially improved by the installation of steel slider beds underneath the belt. These straight beds keep the belt edges straight and thus permit rubber side shields to work effectively.

Problem: Motor and equipment damage on large conveyors.

Solution: Large conveyors such as the flight conveyor required excessive starting currents, and thus were capable of exerting excessive power when problems occurred. This meant that equipment was frequently damaged instead of the relays dropping out before the damage occurred. This problem was solved by the use of current sensing relays to provide current for starting, but then reducing the maximum allowable current so the equipment will trip out before major damage occurs.

Problem: Poor power factor created by the large shredder motors.

Solution: The large shredder motors (1,000 horsepower) on each of the two mills created an unacceptable low power factor at the processing plant. This problem was corrected by the installation of capacitors on the motor supply lines. These were installed at the rear of the motor switchgear and have successfully corrected this problem.

Problem: Excessive wear on the floor of the refuse derived fuel storage bin.

Solution: It is only natural in a storage facility that some of the heavier particles will find their way to the bottom of the pipe or the floor of the facility. The storage bin is unloaded by a series of drag buckets that move along the bottom of the floor and are pulled by a pull ring that is propelled around the outer edge of the storage facility. This is done to prevent the burying of this equipment under the refuse pile. The buckets weigh 300 to 400 pounds each, and glide on the floor with a steel plate which is approximately 5" wide and 4' long (the length of the bucket). Approximately ten buckets are hinged together and there are four strings of buckets in constant motion while the bin is being either loaded or unloaded. This creates a severe wear on the floor of the structure. The initial structure was built with a hardened concrete surface which wore off in less than a year.

The first attempt at resurfacing was to use a hard trap rock from Dresser, Wisconsin, and an epoxy for a binder. The entire floor was surfaced with this material, but most of it was removed in less than six (6) months. Next, two (2) surfacings in different quadrants were tried using a patented cement which contains iron particles, and another quadrant was surfaced with a street asphalt mix. The mix containing the iron particles was very resistant but was subject to break-up. It's believed this breakup was due to the oxidation of some of the iron particles in the concrete. The asphalt quadrant went for an entire year without any substantial reduction in material, except at the inner and outer edges. Since this experience, they have resurfaced the entire bin with asphalt street mix and are particularly pleased, since it is a local product and the price is right. Resurfacing is now scheduled every two years.

Marketing

The key market for Ames is the fuel fraction (RDF) from the waste and its consumption as an energy source by the Ames Electric Utility. It is anticipated that the coal-fired boilers at Ames will be in use for the next 15-20 years, the projected life of the resource recovery facility.

The exchange of funds for the RDF fuel is tied to the price of other fuels bought by the utility and thus is continuously escalating upward. Recent prices paid for coal FOB the Ames yard are $31.00 to $47.00 per ton for western coal (8,000 BTU/lb. and 10,000 BTU/lb.) and $40.80 per ton for washed Iowa coal (10,000 BTU/lb.).

Other products produced by the resource recovery facility are much more volatile. Although the operation has had contracts for ferrous sales the past six (6) years, those contracts are not being offered today. Most metals are now being sold on short term agreements at very unattractive prices. We would anticipate that this situation will continue until the economy moves to higher levels of production.

Paper and box board products are even more volatile than ferrous materials. Although box board has recently become a saleable item for the Ames operation, very little newsprint has been marketed for the past two and one-half years. Prior to this time, newsprint was selling for as high as $90.00 per ton.

Used motor oil has been more stable than the commodities mentioned above. Although the plant does not market a great deal of motor oil, a truck load shipment will normally bring 10¢ to 15¢ per gallon.

Summary

The Ames Solid Waste Recovery System facility has proven that valuable products can be recovered and successfully used through the processing of solid waste. Most of the major problems in a plant of this type revolve around the handling of a very low density material and the fact that the material may contain very abrasive particles. This process is not simple and required a lot of hard work on the part of dedicated people to bring this technology out of its infancy. The salvaging of usable materials from a waste product can provide low-sulfur fuel for coal-fired boilers and saleable metallic products.

The recovering of usable products establishes a conservation ethic of preserving our natural resources. The recovered metallic products are a portion of our nonrenewable resources. With the increased scarcity of suitable land for waste burial, the dwindling of our natural resources, and the need for additional sources of energy, the processing and reuse of waste products offers a potential source to minimize these concerns. Although processing facilities of this type have not been self-supporting, rising costs of fuel and some metals will improve the economic feasibility as an alternative to landfilling practices. The bottom line is that the system works. It processes raw garbage, recovers ferrous metals, produces RDF (fuel) and burns the fuel.

The capturing of new energy sources for our society and the salvaging of non-renewable resources will surely be looked upon by our grandchildren as a commendable undertaking. It is evident that the use of landfills for the disposal of many wastes from our society will continue for some time; it is also evident that land requirement needs can be minimized through the separation and reuse of these materials. Other technologies have learned to salvage or reuse at least part of the waste that they produce. Surely this conservation effort will improve to the point where little or no valuable land will have to be used for the burial of our daily wastes.

References

1 Hamilton, Frank; Kelyman, John. Disc screens. **Solid Waste Management**, May, 1979.

2 Fiscus, Douglas E.; Joensen, Alfred W.; Chantland, Arnold O.; and Olexsey, Robert A. Evaluation of the Performance of the Disc Screens Installed at the City of Ames, Iowa, Resource Recovery Facility. **ASME Solid Waste Processing Conference**, Washington, D.C., May, 1980.

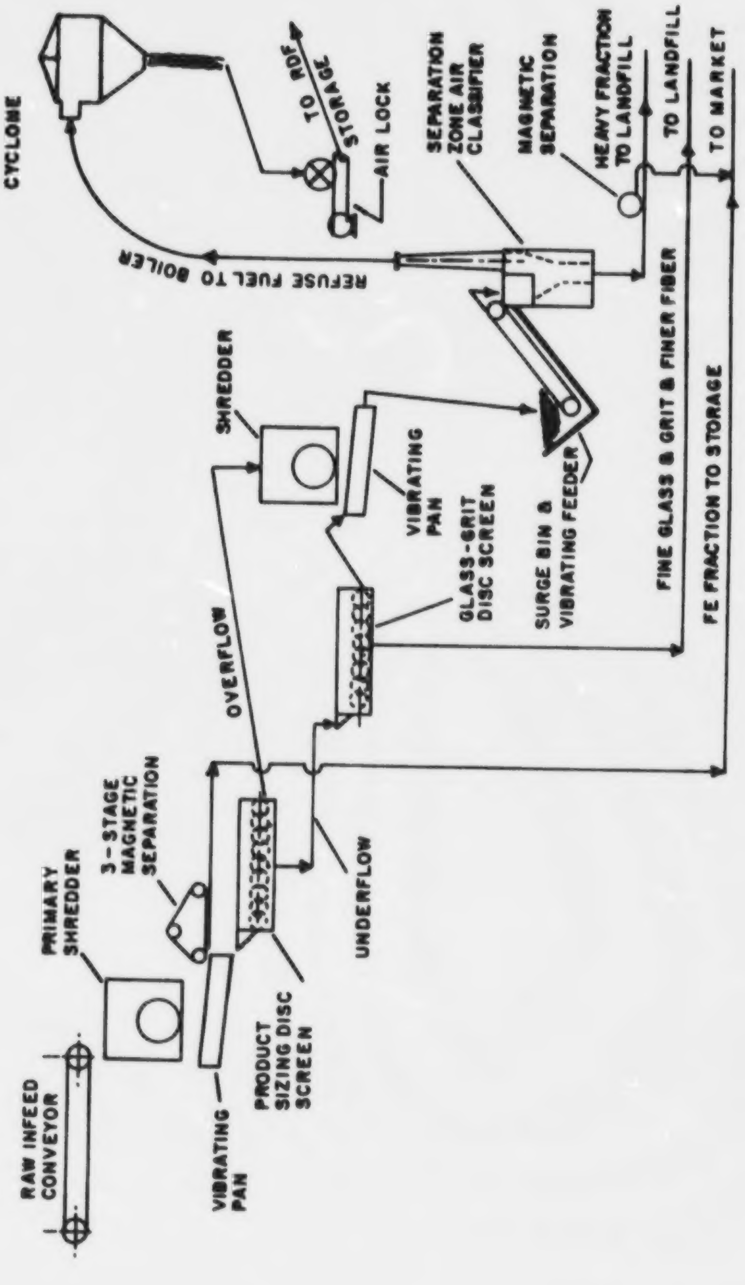
3 Chantland, Arnold O.; Borchardt, Frank A. The Ames Project. **GRDCA Annual Meeting**, Salt Lake City, Utah, September, 1981.

4 Chantland, Arnold O. Solving Refuse-Derived Fuel Problems. **American City and County**, September 1980.

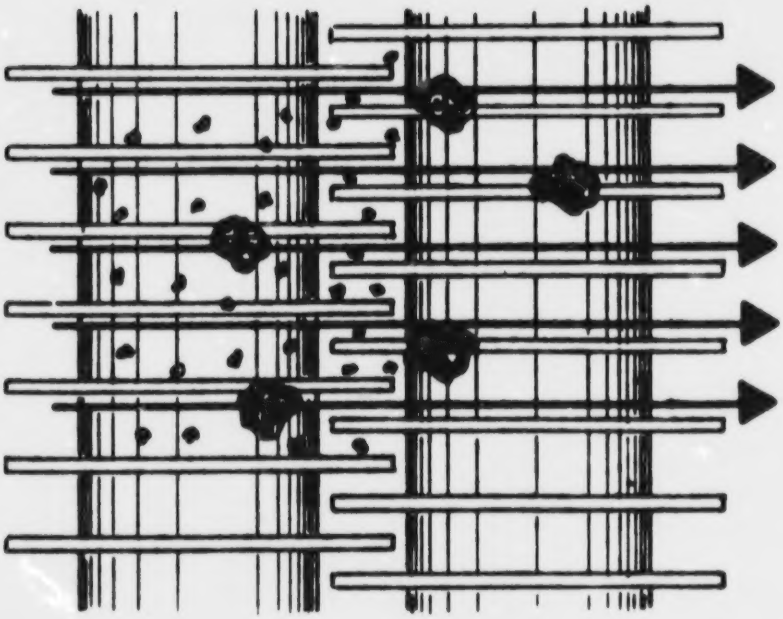
5 Chantland, Arnold O. Ames Experience update – 1981 conference on "Utilizing Municipal Solid Wastes as a Fuel", **University of Wisconsin Extension**, Madison, Wisconsin, December, 1981.

The Ames Recovery System.

figure 1

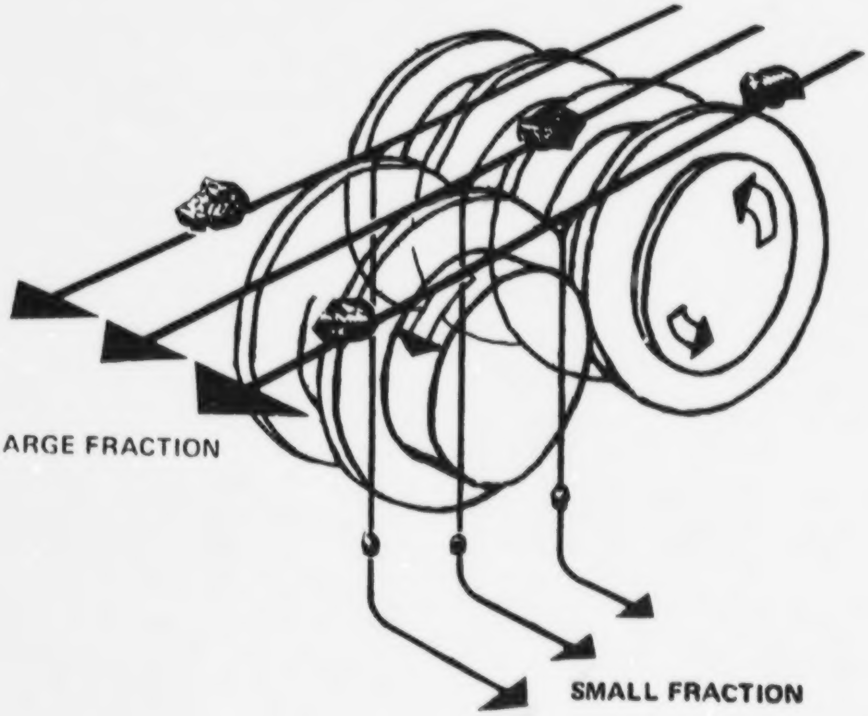


A typical section of the disc screen.[1] **figure 2**



A perspective view of the same screening activity.[1]

figure 3



Appendix "A" Financial

City of Ames Solid Waste Recovery System Data Report Thru Fourth Quarter

Data	Period Ending 12-31		Amount of
Item	1980	1981	Change
Raw Refuse Received	40,076	41,011	935
Materials Separated	(13,296)	(14,240)	944
Net RDF to Storage Bin	26,780	26,771	(9)
Operating Revenues	551,396	603,342	51,946
Operating Expenses	(1,002,570)	(807,819)	(194,751)
Net Operating Expenses	(451,174)	(204,477)	(246,697)
Non-Operating Revenues	340,663	132,354	208,309
Non-Operating Expenses	(541,850)	(522,350)	(19,500)
Total Net Expenses	(652,361)	(594,473)	(57,888)
Operating Revenue Detail:			
RDF Credits	380,003	444,631	64,628
Metal Sales	77,095	80,643	3,548
Wood Sales	1,599	1,254	(345)
Plant Fees	46,941	46,341	(600)
Misc. Revenues	5,245	7,290	(2,045)
Landfill Fees	40,513	23,183	(17,330)
Non-Operating Revenue Detail			
Oil Entitlements	171,834		(171,834)
Governments, EPA & Adjustments	170,787	132,354	(38,433)
Operating Expense Detail			
Shredder Maint.	73,700	50,660	(23,040)
Degritting System Maint.	21,521	21,575	54
Tipping Floor Operation	98,557	57,484	(41,073)
Conveyor Maint.	36,923	28,059	(8,864)
Equip. Rent (Plant Only)	66,403	59,635	(6,768)
Fire Insurance	28,529	17,094	(11,435)
Metal Shipping	46,070	47,362	(1,292)
City Utilities	147,077	139,282	(7,795)
Other Plant Operations	362,394	314,906	(47,488)
Landfill Operations	121,396	71,762	(49,634)
Non-Operating Expense Detail			
Bond Principal & Interest	529,350	509,850	(19,500)
Equipment Reserve	12,500	12,500	0
Electric Power Consumption (KWHr.)	2,306,627	2,052,826	253,801

Ames Solid Waste Recovery System Materials, Revenues & Expenses for Plant Operation

Year	Tons Avail	Process Tons	(%)	Ferrous Tons	RDF Tons	Revenue	Expense	Percent Rev./Exp.
1976	52,000	40,936	78.7	2,868	34,464	$448,721	$1,033,186	43.4
1977	56,780	48,381	85.2	3,008	40,890	498,626	1,047,734	47.6
1978	50,520	37,720	74.7	2,380	28,488	448,227	1,022,632	43.8
1979	49,096	32,010	65.2	1,558	23,059	413,253	1,230,677	33.6
1980	43,684	40,076	91.7	1,794	26,797	659,375	1,397,334	47.2
1981	41,790	41,011	98.1	2,151	26,771	572,982	1,274,744	45.0
6-year Total	293,870	240,134		13,759	180,469	$3,041,184	$7,006,307	

Six year Averages

$/ incoming ton revenue	$12.66
$/ incoming ton expense, net	16.52
% recovery – RDF	75.2%
% recovery – ferrous	5.7%

Capitalization
Ames Refuse Derived Fuel Production Facilities

Processing equipment (1973 dollars)			
Shredding system (include conveyors)	$ 304,000		
Ferrous separators	69,282		
Air density seperator	182,854		
Incoming refuse scale	32,769		
Other plant conveyors	104,600		
Plant crane	24,520		
Pneumatic conveyor of RDF	30,017		
Electric Substation & motor starters	97,343		
Non-ferrous separation system	251,130		
Wood chipper	32,319		
Sub-total	$1,128,834		
Building & installation of equipment (1974 dollars)			
Structure	1,980,664		
Mechanical (include equipment installation)	414,105		
Electrical	314,020		
Sub-total	$2,708,789		
Land	107,841		
Engineering (process plant)	278,903		
Sub-total	$386,744		
Total Process Plant		$4,224,367	
Power Plant Conversion & RDF Storage (1974 Dollars)			
Storage Bin	$656,428		
Boiler modifications	178,989		
Land (no charge)	-0-		
Pneumatic conveying system	134,371		
Mechanical	188,479		
Electrical	342,867		
Engineering	97,993		
Total Power Plant & Storage		1,599,127	
Plant start-up (1975 dollars)			
Miscellaneous equipment (loader, trailer, tools, etc.)	164,827		
Operation (4 month shake-down)	71,603		
Interim financing (mostly interest)	249,975		
Start up costs		486,405	
Total original capital costs			$6,309,899
Facilities modification costs (major items, 1978)			
Dump grate Broiler #7	113,380		
Disc screen system	232,003		
Dust collection system	165,592		
		510,975	
Total Capital Investment			$6,820,874

Appendix "B" Refuse Derived Fuel

Typical Refuse and RDF Classification by Weight

Composition	System Input (Refuse) Before RDS	After* RDS	RDF Output Before RDS	After* RDS
Cardboard	9.16	17.96	10.43	29.06
Paper	37.24	46.50	42.44	49.50
Plastic	5.25	4.29	3.95	5.13
Wood	6.63	10.03	8.21	4.28
Glass	10.38	4.86	6.05	1.44
Ferrous	1.39	0.71	0.21	0.14
Non-Ferrous	0.00	1.81	1.29	0.58
Natural Organic	7.65	4.10	4.21	1.49
Cloth	1.44	0.63	3.54	1.59
Tar	0.04	0.00	0.23	0.00
Miscellaneous (sand, grit, rock, dust, etc.)	20.82	9.08	19.44	6.59

* Sample period 1: 2/24/78 to 4/20/78 *before* addition of rotating disc screens.
Sample period 2: 2/26/79 to 4/16/79 *after* addition of rotating disc screens.

** no material was found in input samples

Note: Although the percentage of combustible material has decreased in some compositions after the rotating disc screen modification, the lost materials were 'fines' (glass, grit, dirt, cigarette filters, paper, and other fine material smaller than 3/8" in diameter).

Rev: 8/80

Fuel Characteristics Before and After Disc Screen Installation[2]

(all valure moisture as received basis)
(before 1978; after 1979)

	Before Air Classification before	after	RDF before	after
Higher heating value kJ/kg	11,614.7	13,769.6	11,408.7	14,209.
Proximate and ultimate analysis – %				
Ash	20.08	12.75	20.99	9.55
Moisture	22.80	20.23	22.06	18.42
Fixed carbon			30.79	56.10
Volatile matter			26.16	15.93
Carbon			28.45	36.67
Hydrogen			6.85	7.42
Nitrogen			0.39	0.34
Oxygen			42.74	43.64
Sulfur			0.34	0.19
Chloride			0.23	0.21

Appendix "C" Equipment

Equipment Description

Processing Equipment	
Shredders	Horizontal 50-ton per hour hammermills; one primary, one secondary.
Conveyors	Metal pan conveyors, rubber trough conveyors, oscillating conveyors, pneumatic conveyors, auger conveyors, rotating disc screens and bucket elevators.
Magnets	Three-stage belted electromagnet; three permanent magnet tail pulleys in the conveying system.
Pneumatic System	Air density classifier, rated at 30,000 cubic feet per minute, pneumatic conveying system to storage bin rated at 8000 cubic feet per minute.
Dust Control	Bag house system and spray nozzles within shredders.
Grit Control	Two rotating disc screens for removal of 'fines'
Non-Ferrous System (inoperative)	Trommel screen with $\frac{5}{8}$ths, $1\frac{1}{4}$ and 4 inch gradations, eddy-current separators, air knife separators.
Related Equipment	
Front End Loader	Mixes refuse on tipping floor, provides infeed to conveyor for shredding.
Woodchipper	4' x 6' box-type chipper, provides wood chips for use as mulch.
Baler	Primarily used for baling cardboard; newsprint is sold loose.
Oil Storage Tank	10,000 gallon underground holding tank for waste oil storage.

Rev: 8/80

Recovery and Utilization of Landfill Gas

by:
Anthony J. Crutcher
Walter Graziani
Conestoga-Rovers & Associates Limited
651 Colby Drive, Waterloo, Ontario, Canada N2V 1C2
(519) 884-0510

Abstract

The recovery and utilization of landfill gas is described commencing with landfill gas production, migration and ultimately with the recovery and utilization of landfill gas. Considerations for determining the feasibility of a landfill gas recovery facility are outlined including required landfill site characteristics, market analysis and regulatory concerns. A case history of the Kitchener Landfill Gas Utilization Project (Kitchener, Ontario, Canada) is described from the initial feasibility studies to the actual sale of landfill gas.

Introduction

As a by-product of the natural decomposition of organic matter, gaseous products are formed. Initially, the decomposition is generally in an aerobic environment however, very shortly after placement the oxygen is consumed by the microorganisms and an anaerobic environment develops. Four stages of gas development occur during this period and are graphically illustrated in Figure 1 (1). Initially, in the aerobic environment the primary gases are nitrogen and oxygen however, as the biological degradation of the waste proceeds and the oxygen is consumed, the primary by-products are that of methane and carbon-dioxide. Typically after reaching the fourth stage, a more steady state gas composition occurs. In the fourth stage the methane concentrations can range between 50 (500 BTU/scf) to 70 (700 BTU/scf) percent and the carbon-dioxide between 30 to 50 percent. The length of time required to meet this stage of decomposition varies from site to site however, in general develops between six months to three years.

The high methane composition of the by-product gas has the potential to be used as an energy source. This gas can be found in many locations where organic material undergoes anaerobic decomposition. However, one of the major sources of this gas is from sanitary landfill sites (landfill gas).

The high combustibility of the methane in the landfill gas makes it a potential hazard in the landfill environment. This gas has the potential to migrate through the soil and eventually enter nearby structures. In the mid to late 1960's the hazards of this landfill gas migration became evident when reported cases of explosions and fires were determined to be caused by landfill gas (2). Since that time, a considerable effort has been undertaken to prevent lateral migration of landfill gas (3,4). Typically, this landfill gas control has been conducted on the periphery of the landfill using a series of passive vents (without power) or active vents (under suction pressure) to release the gas to atmosphere. In some cases, the landfill gas collected from the vents is flared to reduce some of the odor problems. As a result of this flaring, it was recognized that landfill gas had a potential as an energy source.

In mid 1975 the Palos Verdes Landfill Site in California (5) was tested for the potential of landfill gas recovery and utilization. The first commercial landfill gas recovery and utilization system was constructed at this site and this set the stage for future sites to be developed for landfill gas recovery.

Across North America, there are presently, approximately a dozen landfill gas recovery facilities in operation with a further two dozen facilities in the various planning stages. The landfill gas is being used both "as is" with only particulate matter and moisture removal (300 – 550 BTU/scf) or purified to pipeline quality through further removal of carbon dioxide and trace components (900 – 1000 BTU/scf).

Site Analysis

To assess if a landfill site is suitable for the recovery of landfill gas, there are many factors which must be addressed, which include:

1 Type and quantity of waste

2 Depth of waste

3 Method of placement

4 In-situ moisture content

5 Age of landfill

6 Type and depth of cover soils

7 The pH of the waste

Generally speaking, only landfills having greater than one million tons of domestic (or high organic components) waste deposited, presently being operated or closed no longer than five years and having a depth of refuse no less than 40 feet are considered feasible for evaluation for gas recovery. However, it should be noted that each site must be evaluated on its own merits.

The rate of methane production varies considerably from site to site and is encouraged by a high percentage of biodegradable materials and moisture content. Theoretically, it has been calculated that methane yields per pound of wet refuse range from 1.5 to 4.3 scf (6). It must be recognized that not all of the landfill gas generated can be recovered due in part to such things as natural diffusion through the cover and sides of the landfill, and it is impractical and economically unviable to recover the complete amount of gas due to the number of wells, extent of piping systems, etc. It has been found that at operating landfill gas recovery facilities, the methane recovery rates range from 0.01 to 0.07 scf per pound of refuse per year (7).

If a landfill site meets the requirements as being potentially feasible for gas recovery, it is necessary to conduct landfill gas pumping tests to verify gas composition and recovery rates. These pumping tests will provide design base detail required for the overall landfill well placement design for the site, and the quantity and quality of recoverable landfill gas (8).

Market Analysis

The recovery of landfill gas and the ultimate utilization requires the necessity of having a viable market for the gas. There are three primary categories of use for methane from landfills (9). First is the direct sale of partially cleaned-up medium BTU (500 BTU/scf) gas to industrial customers. Second is utilization of medium BTU gas as a source of fuel for electrical generation. Third is the conversion of landfill gas to pipeline standard gas for injection into nearby utility company pipelines. Other potential uses and variations of the above uses include:

1 Steam generation as a source of heat or for electrical generation.

2 Upgrading gas to minimum 900 BTU/scf for compression, storage and use as a vehicle fuel.

3 Conversion of landfill gas to liquified natural gas (methane).

4 Conversion of landfill gas to methanol (methyl alcohol).

5 Direct combustion for space heating.

In assessing the market for the landfill gas, it is necessary to look at the average quantity of gas required during the year and the associated fluctuations (peak demands), the total quantity of gas used per year, how market conditions affect this gas usage, and the price that would be paid for the landfill gas. Assessment of the market will provide an indication of the revenues that could be expected from the sale of the landfill gas. After this evaluation an economic analysis of the overall project can then be performed.

There are several factors which can make the marketing of landfill gas difficult such as, the skepticism of purchasers to long term contracts, the uncertainty of predicting long term gas generation, fluctuations in the composition of the gas or users' demand, the high cost of transporting the gas which requires close proximity to the gas source and the public perspective to using landfill gas.

Regulatory Concerns

The use of landfill gas may on the first instance sound very desirable and feasible however, there are many regulatory concerns which must be addressed in the feasibility analysis of such a facility. These regulatory concerns can take the form of:

1 Environmental concerns dealing with air emissions and disposal of the condensate water

2 Safety concerns with respect to the installation and operation of gas system

3 Health concerns with respect to trace components within the gas

4 Franchise concerns with respect to distribution of landfill gas

5 Landfill approval requirements for the installation and operation of a landfill gas system

6 Taxes which may or may not be imposed on the sale of landfill gas

Due to the relatively new nature of the recovery and utilization of landfill gas, the present legislation which is in place, in general, does not apply directly to landfill gas. Therefore, the Acts and Regulations have to be interpreted with respect to the use of landfill gas and this interpretation not only delays the project but could also jeopardize the feasibility of the project.

Case History – Kitchener Landfill Gas Utilization Project

The Kitchener Landfill Site is located in the City of Kitchener, Ontario, Canada and comprises an area of approximately 75 acres having a disposed domestic waste volume of approximately 2 million tons. The landfill was operated by the City of Kitchener from 1958 to 1974 and subsequently by the Regional Municipality of Waterloo from 1974 to 1978 at which time it was closed. Figure 2 illustrates the landfill setting and the gas recovery system.

As can be seen from Figure 2, the landfill is divided into two sections by an HEPC (Hydro Electric Power Corridor) right-of-way. The northern portion of the site, having an area of approximately 50 acres was filled from 1958 to 1972 having a disposed waste depth of approximately 140 feet. The lower 30 feet of this disposed waste is comprised primarily of domestic refuse with the remaining 100 feet being filled with construction rubble and inert waste. The southern sector of the landfill site comprises an area of approximately 25 acres and has a depth of refuse of approximately 40 feet. This portion of the site was operated from 1972 to 1978 and received primarily domestic waste.

The in situ upper overburden consists of a silty sand. Due to the relatively high permeability of the soil, gas migration laterally away from the landfill site has been a major concern to the neighbouring residences. To help prevent this gas migration, various gas control systems have been installed around the site. To date, the Regional Municipality of Waterloo has spent on the order of $700,000 on the control of this off-site migration of landfill gas.

In 1979, a concrete pipe manufacturer [Bestpipe (A Division of Lake Ontario Cement Limited)] expressed an interest in using the landfill gas generated at the Kitchener Landfill Site to fuel their industrial boilers which were used for the kiln drying of concrete pipe. Preliminary discussions with the Regional Municipality of Waterloo were undertaken and the Region indicated that they would be willing to form an agreement with Bestpipe for the recovery and utilization of this gas. However, Bestpipe was to be responsible for the capital and operating cost of the system and the Region would negotiate with Bestpipe a royalty fee for the use of this landfill gas. A feasibility study was conducted for Bestpipe by Conestoga-Rovers & Associates Limited which indicated that Bestpipe could have a simple return on their investment in about five years if their total natural gas usage at the plant was converted to landfill gas. However, it was also noted that there were uncertainties with respect to landfill gas composition and the length of time that gas would be produced. Bestpipe decided, given the economic conditions at the time and the uncertainties of landfill gas utilization, that it would be unwise to proceed with the gas project on this basis.

The Regional Municipality of Waterloo was still interested in pursuing the landfill gas recovery and utilization at the Kitchener site. The Region could foresee that such a system may help alleviate some of the potential gas migration problems at the site. Therefore, the Regional Municipality of Waterloo and the Ontario Ministry of Energy contracted Conestoga-Rovers & Associates Limited to conduct pumping tests at the landfill site to determine the gas quantity and composition and the technical feasibility of recovering the gas from the site. The results of the pumping tests indicated:

1 That there is sufficient quantity and quality of recoverable gas at the Kitchener Landfill Site to supply Bestpipe with unprocessed landfill gas for use as fuel in their industrial boilers (approximately 1 x 10^6 scf/day of 350 BTU/scf landfill gas).

2 That a landfill gas recovery rate of 0.17 scf per lb. of refuse per year be used as the design gas recovery rate for the Kitchener Landfill site. This gas recovery rate is equivalent to 0.06 scf of methane per lb. of refuse per year.

3 That the gas wells should be sized for a maximum recovery rate of 25 cubic feet per minute.

4 That gas recovery be placed primarily on the southern sector of the landfill site due to the more recent refuse and ease of access.

5 That given the time of placement of the refuse, it could be expected that good quality gas (> 30% methane) would be generated on the order of ten more years.

The Regional Municipality of Waterloo then approached Bestpipe on the basis that the Region of Waterloo finance the capital and operating expenditures at the landfill and Bestpipe finance the capital expenditures on their property. The gas would then be sold to Bestpipe with the selling price having an economic advantage over that of natural gas. Bestpipe agreed in principle with the above arrangement.

A more detailed economic analysis of the project was undertaken and the Region of Waterloo applied for financial assistance from the Federal Government (Environment Canada) under the DRECT program (Development and Demonstration of Resource and Energy Conservation Technology) for the design and implementation of a gas extraction and utilization system at the Kitchener Landfill Site. Due to funding constraints, the system was divided into two phases having a preliminary total capital cost estimate of approximately $480,000, of which Bestpipe was responsible for approximately $52,000 of that cost. The annual operating and maintenance costs were estimated at $35,000.00. The Region was awarded a $200,000.00 grant under the DRECT program. The Region of Waterloo then contracted Conestoga-Rovers & Associates Limited to undertake the detailed design of the gas system.

Figure 2 and 3 present a schematic view of the gas recovery and utilization facility at the Kitchener Landfill site. Figure 4 presents a typical gas recovery well detail.

The Region of Waterloo based upon the preliminary cost estimates, negotiated with Bestpipe a selling price for the landfill gas, based on the criteria that the Region would have a simple return on investment of approximately 5 years (capital cost minus DRECT grant). The selling price was negotiated to be $1.35 per thousand cubic feet landfill gas at 350 BTU/scf. The selling price also allows for variations in price as a function of methane concentration. This selling price is equivalent to approximately $3.85 per thousand cubic feet of natural gas (1000 BTU/scf) which was the selling price of natural gas in late 1981. This price for landfill gas would become effective when the operation went on line in 1982 and apply until July 1983 when annual 10% increases in the landfill gas price occur. An agreement was written on this basis for a five year period, after which time the agreement would be renegotiated.

It was recognized by Bestpipe that the selling price for the landfill gas had an initial economic advantage over natural gas which would improve further with time, assuming the price increases in natural gas would be greater than 10% per year.

After the above agreement was formulated, the landfill gas recovery and utilization system was designed and tendered. The total cost of the project escalated significantly from the preliminary cost estimates. The actual Phase I cost and the estimated Phase II cost rose to approximately $600,000 an increase of $120,000 or 25% over the preliminary estimates. A review of the economic analysis indicated that the simple return on investment to the Region would not occur until approximately the seventh year of operation.

To assist the Region of Waterloo and Bestpipe with the increased costs of the project a $40,000 grant from the Ontario Ministry of Energy was received for the Phase I portion of the project.

Prior to construction commencing at the landfill site it was necessary to contact various regulatory agencies to obtain approvals for various portions of the project and identify what constraints may or may not apply to the recovery and sale of landfill gas. The following is a listing of the various regulatory agencies which were involved with respect to this landfill gas project.

1 Ontario Ministry of Energy (Ontario Energy Board)
  - involved in evaluating if landfill gas transport imposes on the franchise rights of the natural gas supplier

2 Ontario Ministry of Consumer & Commercial Relations
  a) Fuel Safety Branch
    - responsible for determining code requirements with respect to the landfill gas system and a license to distribute the landfill gas
  b) Pressure Vessels Safety Branch
    - involved in evaluating the conversion of the boiler to landfill gas.

3 Ontario Ministry of the Environment (Approvals Branch)
  - involved with three aspects which dealt with air emissions, amendment to the certificate of approval for waste disposal site and the sewering of the condensate water.

4 Ontario Ministry of Labour
  a) Construction Health & Safety Branch
    - involved with respect to safety concerns during the construction of the landfill gas line
  b) Industrial Health & Safety Branch
    - involved in reviewing the landfill gas system design

5 Department of Consumers & Corporate Affairs (Federal) (Weights and Measures Branch)
  - involved in evaluating the necessity of approvals for the metering of the landfill gas

6 Ontario Ministry of Natural Resources
  - evaluation of the landfill gas project with respect to licenses to produce oil or gas for sale

7 City of Kitchener
  - evaluated the landfill gas project with respect to the franchise rights of the Municipally owned natural gas distribution system

As can be seen from above, the approval requirements for this system were extensive. It was found that the regulatory bodies were not familiar with the use of landfill gas and to obtain a definite answer with respect to the approval of the system was both difficult and time consuming. However, all the necessary approvals were obtained.

In July 1982 the landfill gas utilization system commenced construction and was essentially complete by November 1982. A considerable delay in the construction occurred due to time delays in receiving and installing some of the specialty equipment.

In early December 1982, the system went into full-time operation. At the time of writing this paper (December 1982), the system was still requiring some "debugging", however, in general it was operating satisfactorily. The landfill gas concentration to Bestpipe was found to be relatively stable at approximately 35%-40% methane (the design was based on 35% methane). The gas well field was not showing any signs of being "mined" of landfill gas and appears to have sufficient gas to meet the needs of Bestpipe. However, it should be noted that only long term pumping of the well field will verify both the gas concentration and the effects of mining.

To determine the long term effects on the boiler from the use of landfill gas, the Ontario Ministry of Energy funded a study to be conducted by Conestoga-Rovers & Associates Limited to assess the corrosion effects of using landfill gas in the boilers. There are two types of corrosion which are of possible concern using this type of fuel. The first type of corrosion is termed high temperature corrosion. Various components within the gas could possibly react with oxygen at elevated temperatures after burning and could cause plating of materials on the fire tubes of the boilers. The second type of corrosion is wet corrosion. This is the condensation of water from the gas mixture at lower temperatures. This water could possibly mix with different water soluble components within the gas and create acidic solutions. To assess these two types of corrosion, selected fire tubes within the boiler were removed and replaced with new tubes. Some of the removed tubes were analyzed for background conditions. At selected time intervals, the tubes will be removed and analyzed for the two types of corrosion.

As discussed previously in this paper, the Regional Municipality of Waterloo presently operates gas control systems at the landfill site. It is hoped by the Region that the gas recovery system will make some of the gas control systems redundant. To determine if in fact the gas recovery system negates the necessity of the gas control system, the Ontario Ministry of the Environment contracted Conestoga-Rovers & Associates Limited to evaluate the effectiveness of the recovery system to control off-site landfill gas migration. The study commenced in September 1982. The study involved the installation of on-site and off-site gas monitoring probes from which gas concentrations, pressures and temperatures are monitored on a regular basis. Four conditions are being evaluated at the landfill:

1. No gas control or gas recovery system in operation
2. Gas control system in operation only
3. Gas recovery system in operation only
4. Both gas control and gas recovery system in operation

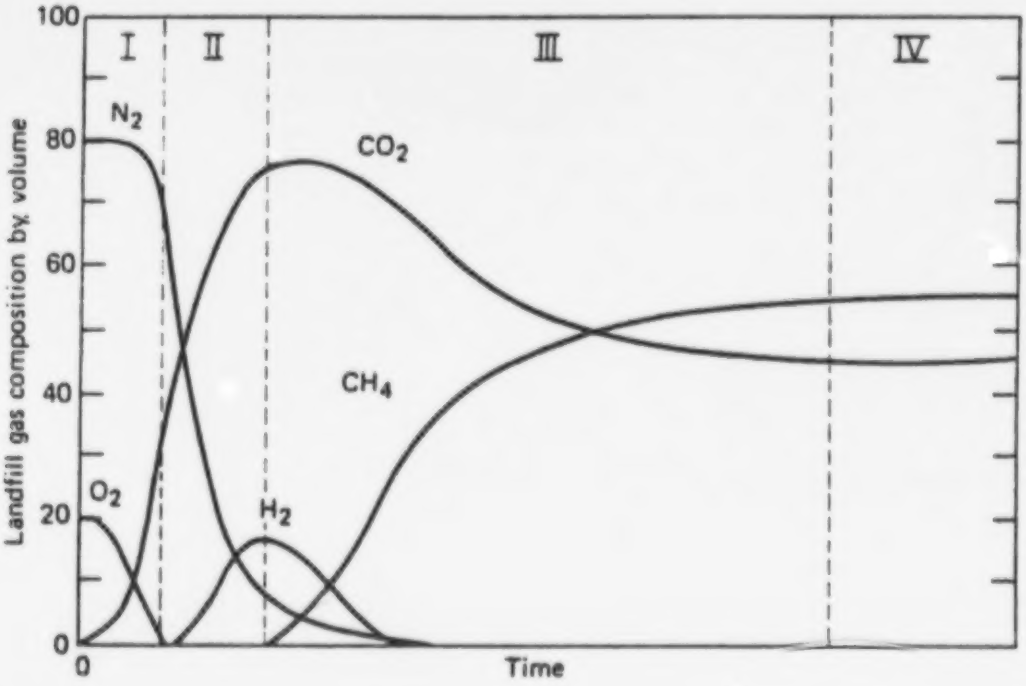
The above two studies are presently on-going with preliminary results being available in March 1983.

References

1. Farquhar, G.J., and Rovers, F.A. "Gas Production During Refuse Decomposition", **Water, Air and Soil Pollution,** Volume 2, 1973.
2. First, M.W., Viles, F.J., Levin, S. "Control of Toxic and Explosive Hazards in Buildings Erected on Landfills", **Public Health Reports** V.81 N.5, May, 1966.
3. Nosanov, M.E., White, R.L. "Gas Control and Beneficial Use of Completed Landfills", **Public Works,** November, 1975.
4. Solid Wastes Management "Preventing Methane Explosions at Landfill Sites", **Solid Wastes Management,** June, 1977.
5. Bowerman, F.R., Rohatki, N.K., and Chen, K.Y. "A Case Study of the Los Angeles County Sanitation Districts Palos Verdes Landfill Gas Development Project", **Environmental Protection Agency/NERC,** Cincinnati, Ohio, 45268, February, 1977.
6. The John Hopkins University "Landfill Methane Utilization Technology Workbook", Prepared by: The John Hopkins University Applied Physics Laboratory. Prepared for: **U.S. Department of Energy,** February, 1981.
7. Stearns, R.P. "Landfill Methane: 23 Sites are Developing Recovery Programs" **Solid Wastes Management/ RRJ,** June, 1980.
8. Crutcher, A.J., McBean, E.A., and Rovers, F.A. "The Impact of Gas Extraction on Landfill Generated Methane Gas Levels", **Water, Air and Soil Pollution** 16 (1981).
9. Mandeville, R.T. "Landfill Gas Utilization and Market Alternatives", proceedings from New York State Association for Solid Waste Management – **Spring Program, Rockville Centre, New York** May 18-19, 1981.

Landfill Gas Composition with Time

figure 1



I – AEROBIC

II – ANAEROBIC, NON METHANOGENIC

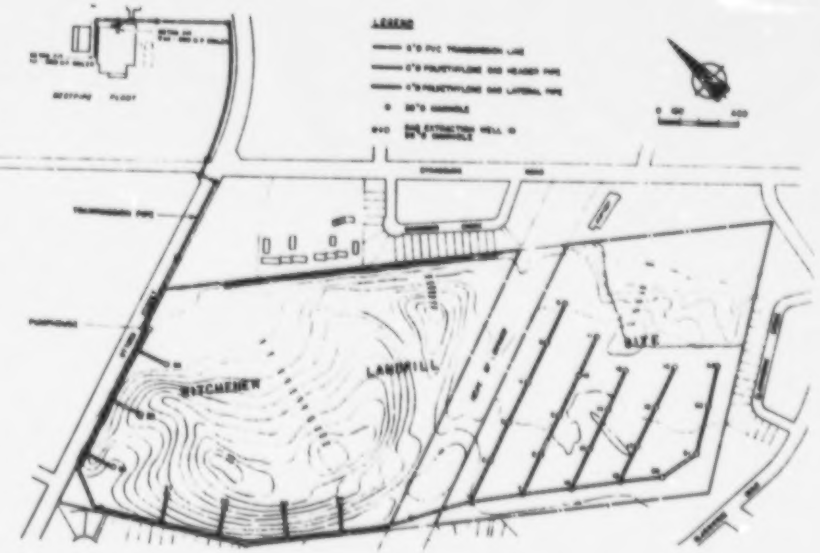
III – ANAEROBIC, METHANOGENIC, UNSTEADY

IV – ANAEROBIC, METHANOGENIC, STEADY

AFTER FARQUHAR G.J. AND ROVERS F.A., 1973 (1)

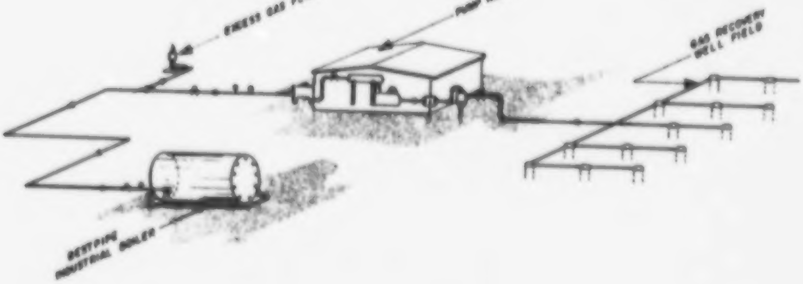
Schematic of Gas Recovery System Kitchener Landfill Site

figure 2



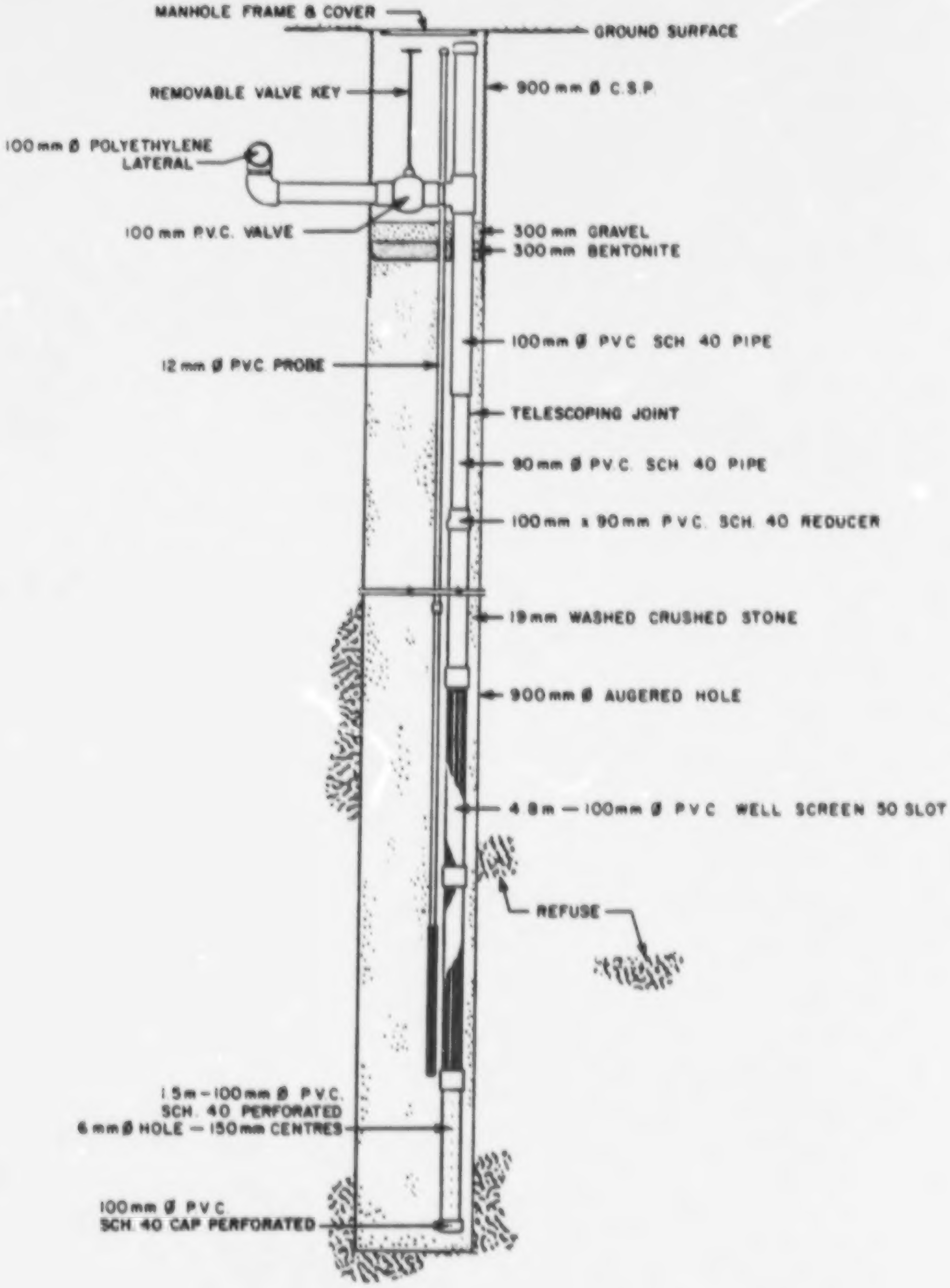
Schematic of Gas Utilization System Kitchener Landfill Site

figure 3



Schematic of Gas Recovery Well Kitchener Landfill Site

figure 4


MANHOLE FRAME & COVER
GROUND SURFACE
REMOVABLE VALVE KEY
900 mm Ø C.S.P.
100 mm Ø POLYETHYLENE LATERAL
100 mm P.V.C. VALVE
300 mm GRAVEL
300 mm BENTONITE
100mm Ø PVC SCH 40 PIPE
12 mm Ø PVC PROBE
TELESCOPING JOINT
90 mm Ø PV.C. SCH 40 PIPE
100mm x 90mm P.V.C. SCH. 40 REDUCER
19mm WASHED CRUSHED STONE
900mm Ø AUGERED HOLE
4.8m — 100mm Ø PVC WELL SCREEN 50 SLOT
REFUSE
1.5m – 100mm Ø P.V.C. SCH. 40 PERFORATED 6 mm Ø HOLE — 150mm CENTRES
100mm Ø P.V.C. SCH. 40 CAP PERFORATED

Operating Experience at the St. John's University Energy from Waste Project

by:
Father G. Tavis
St. John's University
Collegeville, Minnesota

Abstract

St. John's University, Collegeville, Minnesota made its decision to purchase a BASIC ENVIRONMENTAL ENGINEERING, INC. Solid Waste Boiler for environmental, technological and economic reasons. The vote at St. John's for the University to enter into a contract with BASIC was colored by the values of the institution, its intention to be of service, its desire to play a role in helping solve a major social problem of our time. In signing the contract, it was made clear to BASIC that St. John's would be the place where they could perform Research and Development (R&D).

R&D has been underway at the St. John's plant since startup. At this time BASIC has completed R&D on the moving floors, ash removal scoop, charging ram, cupola caps on emergency stack, ID fan. Each is performing at the desired level. R&D is still underway on air seals, temperature levels, water filled ash pit and clinkering.

St. John's has conducted R&D on problems not associated with BASIC equipment: a steam delivery problem and a possibility of venting the exhaust gases into our 175 foot stack. Further lessons have been learned by St. John's and are being shared.

With each step the R&D is bringing the equipment closer to its ratings and closer to our expectations. Financially, the first year has not been profitable, but the R&D is moving us closer and closer to that accomplishment.

Introduction

When the President of St. John's University addressed a group of people who were directly involved with the Solid Waste Boiler at a luncheon on Dedication Day, he said that one of the reasons St. John's was interested in this project was, "that it gave this educational institution an opportunity to participate in the Research and Development necessary to solve one of the biggest social problems of our day." I have chosen to start with this statement because, as the use of the term Research and Development (R&D) illustrates, the situation at St. John's is indeed special.

The feasibility study conducted by St. John's concluded: 1) that there were no totally proven machines on the market for burning solid waste; that some of the systems held promise; that St. John's could play a role in the R&D with one such machine; 2) that since St. John's had savings only on the energy side of the problem it needed the top steam producer that was available.

The BASIC ENVIRONMENTAL ENGINEERING, INC. Model 3000M was selected for environmental, technological and economic reasons. With that selection St. John's agreed to provide the place where BASIC could perform needed R&D. This was to be BASIC's first unit dedicated solely to burning municipal solid waste; their second designed for continuous burn; their first equipped with three heat recovery units – the radiant section in the first burn chamber, the water tube convection boiler following the burning areas and the economizer just ahead of the ID fan.

Why Would St. John's Choose to Get Involved?

To understand why St. John's University would install such a machine, you must, to some degree, understand St. John's. The campus is located in the country, totally by itself, amidst 2500 acres of woodland and lakes. The campus is shared by St. John's Abbey, the largest Benedictine Monastery in the world; St. John's University, a liberal arts college with a graduate school in theology; St. John's Preparatory School; The Liturgical Press; KSJR, the original station of Minnesota Public

Radio; and the Institute for Ecumenical Research. There are about 2300 students in the schools; about 1850 persons make the campus their residence. In many ways St. John's is like a small town with its own district heating system, electrical distribution system, water system, sewage system, and waste water treatment plant. The central power plant has some cogeneration equipment which supplies about 25% of our electricity.

While the feasibility study was underway at St. John's, questions from official groups had relatively little to do with finances. Questions primarily addressed environment; the state of the art in technology; the need for leadership in this field; the finite nature of most energy resources; the immediate solid waste problem of our county and state; the public relations required with students, faculty, and neighbors; long-term financing available to us but to no one else in our area. In these questions and concerns you see some of the values which guide the institution.

From a financial point of view it was demanded that financial feasibility be demonstrated at a conservative level. Our analysis indicated that the BASIC Solid Waste Boiler should pay off the investment within ten years presuming that it would at least work at the 75% level of its ratings. That was sufficient for financial feasibility, but it was not indicative of a financial bonanza.

The vote at St. John's to proceed was colored by our values, our desire to be of service, and our desire to play a role in helping solve a major social problem. It was a clear indication of the institution's interest in taking an educational and leadership role. It was a matter of standing up to be counted on an issue of great importance.

Why BASIC?

Given the background and spirit of St. John's, why would they choose BASIC ENVIRONMENTAL ENGINEERING, INC. and its obvious need for R&D?

In researching the field, Dan Weber, Chief of the Power Plant; Fr. James Tingerthal, OSB, Physical Plant; and Fr. Gordon Tavis, OSB, Treasurer were most directly involved. Since we do not have a solid waste problem, we were coming strictly from the side of energy. How could we best use a local abundant fuel called solid waste? BASIC appealed to us since in theory it was not an incinerator with a heat recovery unit attached. Rather it was an innovative new approach to building the best boiler possible for that new fuel called solid waste. With its three heat recovery units the engineers predicted that it would make more steam per pound of waste than other modulars on the market. An additional attraction was that a BASIC unit could be equipped with Minnesota made Deltak Boilers. The Deltak choice also allowed bare tubes in the convection boiler, our preference.

Environmentally, BASIC incinerators had consistently passed air quality tests without cleanup devices and St. John's had a guarantee that BASIC would supply and install a collector if such was needed. The temperatures of the three burn chambers were aimed at a clean burn without producing detrimental flue gas emission problems.

BASIC equipment had heavier gauge steel and appeared to be more durable. Their track record indicated that every machine installed was still in operation. BASIC is outfitted exclusively with mechanical systems and air controls, rather than hydraulics. Not only did we prefer these systems for simplicity of construction, but the absence of fire hazard was desirable.

Finally, we favored BASIC's answer to the most difficult problem facing the modular designer: once the waste is inside, how do you move it through the machine: how do you get the ash out? The answer BASIC gave to each was brand new: using a moving floor which pulses forward only to stop abruptly while the debris inches forward with the force of the original motion; use a backhoe-like shovel to move down into the water pit which provides air seal at the back end of the machine, scoop up ash, drag it up an incline to a waiting receptacle.

In the realm of financial feasibility BASIC was the only machine that our calculations indicated could totally retire its debts within 10 years when operating at 75% of the equipment's ratings. We chose these tough constraints because of the poor performance records of resource recovery plants in general.

Environmentally, technologically and economically our study said BASIC should give the best results once the R&D was completed.

The BASIC 3000M

Before turning to the problems and the R&D, let me first describe the BASIC Solid Waste Boiler Model 3000M. As Mr. John Basic puts it, the Solid Waste Boiler has three systems, each with three components, linked together and controlled by a microprocessor. The St. John's unit sits within a building attached to the central power plant on the west side of our campus. The building matches local building "codes." Solid waste coming into the plant is weighed. The haulers dump it on the tipping floor and a Bobcat skid-steer loader is used to move the waste into the hopper of the solid waste boiler. From there on the BASIC 3000M takes over. (See Figure 1)

Three mechanical components handle the fuel. 1) Loading Mechanism. A door on the top of the hopper closes, the ram with rack and pinion drive mechanism moves the waste into the fire box. 2) Moving Floor. Internally the waste rides on a refractory covered floor which is suspended so it swings backward and forward. At rest, in gravity position, air bags on one end pump up to propel and swing the floor toward the rear of the unit. The swinging action of the floor is stopped abruptly 5 inches later. According to an elementary physics principle, the forward force transmitted to the elements on the floor continues even though the floor itself stops. The result, the waste on the floor inches its way toward the ash pit. The St. John's unit has two moving floors. (Some BASIC units have three moving floors.) 3) Ash Scoop. The ash falls off the rear of the lower moving floor into a water quench. It filters down to the bottom of the water filled ash pit. A large shovel moves down a chute connected to the ash pit and drags ash up the incline, draining the water as it goes. The ash is deposited in three yard containers for transference to trucks that will take it to the landfill.

Three combustion chambers burn the fuel. 1) The first burn area is the fire box. In this chamber pyrolysis takes place. Many of the highly volatile substances are immediately combusted in this chamber at temperatures over 1500°F. 2) Second burn chamber, the first reburn section. Unburnt gases in the flow of the exhaust are excited into combustion in this section, which burns at about 2000°F. The higher temperature gasifies hydrocarbons still in vaporous form. 3) Third burn chamber, the second reburn section. Combustion of the vapors now gasified is complete in this section.

Three heat recovery units extract the energy present. A Deltak Dina Boiler Model 1152R, built in two sections generates steam. 1) Radiant Section. The fire box walls and ceiling are covered with boiler tubes. These not only capture radiant heat energy present; they provide a means to a) control the temperatures of the fire box thus avoiding slagging and b) allow slower velocities thus entraining fewer particles.
2) Convection Section. Following the combustion chambers the exhausting gases are directed through the convection section. Gases enter at about 2000°F, exit at about 600°F. Saturated steam is produced at 175 psi, 365°F. 3) Economizer. Exhausting gases pass through the economizer just ahead of the induced draft fan. This heat recovery unit captures energy to preheat the return water before it is placed in the boiler. Gases exit this unit at about 400°F.

Microprocessor. A programmable Texas Instruments microprocessor directs and controls the loading of waste, air mix, floor movement, ash removal. It is the "brain" of the unit unifying its activities.

Problems – R&D by BASIC

At the time of this writing the Solid Waste Boiler at St. John's has been in startup R&D for about one year. No one at St. John's fully anticipated the degree of R&D to be undertaken by BASIC, but in each instance the problem has been isolated and either eliminated or brought more and more under control. That statement is not intended to say that the R&D is completed, because in certain instances the solutions allow and sometimes cause other problems to surface.

1 Moving Floor – Problem: Flow of waste and excessive jolting.
The early R&D was primarily centered on the moving floor. Several major revisions were made to the shape, the refractory, the propelling mechanism, the catching mechanism, the suspension, and to the access space before the desired flow was reached while eliminating the shock element from the pulsing action.

2 Air Seals – Problem: Leaks.
Most of the original problems were caused by alterations to the floor. However, even after that phase of R&D was complete, this problem remained. Design changes have improved the seals, but it is still a problem.

3 Inability to reach and hold rated temperatures – Problem: Burning too much supplementary fuel.
Only after the floor and air seal R&D was well along was it possible to diagnose this problem and to begin planning solutions. Several actions have been taken: input air for the first burn chamber has been preheated to a higher temperature; the gases in the second burn chamber have been excited to burn more completely; a throttling mechanism to allow burning somewhat below capacity without requiring supplementary fuel have all been installed. It is too recent to comment on their effectiveness.

4 Ash Removal – Problem: Motor and gear box failure.
As it turned out, what is listed under problem was really the symptom. The problem was in the ash pit. The abrasives in the ash caused a wearing away of about one inch of surface. The result was a one inch over-hang on which the ash scoop would bind. The ash pit was lined with steel eliminating the problem. A heavier duty unitized drive mechanism eliminated the symptom.

5 Ram – Problem: Too much movement in framework.
A bug in the mechanical drawing. Brace had been missed.

6 **Cupola Caps – Problem: Failure to open.** During an emergency shut down the opening mechanism failed. Being on the roof, the drive cylinders were exposed to the elements and corroded. These are now stainless steel and encased in boots to keep them clean and functional. The speed control mufflers which govern the cylinder's movement have also been moved out of the elements.

7 **I.D. Fan – Problem: Sending exhaust inside the plant.** Poorly constructed joint between I.D. fan and stack. A steel line was placed inside the joint and the element was re-covered.

8 **Water filled Ash Pit – Problem: Debris floating.** The problem exists within the first burn chamber when the ash falls into the water filled ashpit. The air seal for the rear of the machine protrudes into the water keeping the air out, but keeping anything that floats in. The surface tension on the water increases as it becomes more and more muddy. The result, spray cans and other objects ride on the surface. Water jets have been installed to drive the floaters below the surface and under the air seal. The situation is somewhat improved, but a better solution is being sought.

9 **Clinkering – Problem: Occasionally solid waste binds together without burning.** Usually this mass of solid waste temporarily sticks to the floor and won't move through the machine. It has to be pried loose after the floor has been cleared. Feeding smaller amounts more often helps. Floor shape changes have helped. Refractory changes have helped. Better floor movement has helped. Hotter air input mentioned in #3 should help and the throttling down capability in #3 should make it easier to clear the floor. But, occasional clinkering is still an operating problem.

Problems – R&D by BASIC

St. John's has been engaged in R&D concerning two major problems that have occurred beyond the BASIC equipment.

1 **Steam Delivery – Problem: System senses excessive steam pressure in the boiler; shuts down.** The boilers are capable of making the rated steam capacity but the piping, valves, etc. connecting the boiler to the main steam header of the plant does not appear to be able to deliver it. The steam capacity is rated at 16830 lbs./hour. On several occasions we have substantially exceeded that rating. On one occasion it peaked at 20,000 lbs./hour. But the more usual occurrence is for the machine to go into automatic shutdown to relieve the build-up of steam pressure when it consistantly exceeds 15000 lbs./hour. R&D is still underway.

2 **Exhaust Gases – Problem: Curling back to the ground and into the buildings.** No matter how clean the gases are which come from a furnace, no one wants to live in that gaseous stream. The problem seems to occur for several reasons. The lay of the land just happens to put some of our buildings uphill from the power plant. The exhausting gases being only 400°F, cool rapidly and sink back toward the earth. The slightest inversion causes an immediate downturn. – The original three boilers at St. John's are natural draft units with a 175 ft. stack. There is sufficient capacity in that stack, thus we are in the process of engineering the venting from the Solid Waste Boiler to the breeching of that stack.

Still needed – a) Analysis of the screened ash to see if it can qualify for some use, or at least for a lesser demanding landfill (demolition rather than sanitary landfill). b) Installation of some emergency lights for occasions when the local electricity utility is temporarily down. c) Use for the heat factor of the steam which in the summer is merely being dissipated by a condensor.

Additional Lessons Learned by St. John's

1 Solid waste is a most difficult fuel. It is inconsistent. For example, yard and garden wastes that theoretically could be excellent fuel, come in green with no time for drying. It is like throwing a wet blanket on the fire. The moisture content of these and other elements is often excessive. – The number of non-combustibles varies. As such non-combustibles have not caused any special problems, but they have not added Btu's or helped the process. – Snow hasn't been too much of a problem, but rainy weather is the scourge of the Solid Waste Burner. Household waste has come in so wet, we have had to add coal to it. Literally, unless there is simultaneously a large supply of dry high Btu waste, the modular unit will burn supplementary fuel wide open and still have trouble burning the wet waste.

2 When making arrangements for the supply of waste, St. John's was approached by the City of St. Cloud. A contract was written and the city trucks have provided about 75% of the waste burned to date. Since the city trucks only pick up residential waste, the mix being burned was

not what is typically defined as Solid Waste. By definition Solid Waste includes wastes from shopping centers, restaurants, office buildings and commercial enterprises as well as households. Since the summer rains, which especially drench household waste, steps have been taken to reduce the residential portion while increasing other elements. In the future our fuel should be closer to "Solid Waste".

3 What is the average Btu per pound of solid waste? After a year of burning, that question is still unanswerable. The only answer possible is; it depends. It depends on the time of the year, on the weather, on the mix of household waste vs. commercial waste, on how many wood burning stoves there are in the neighborhood of origin, on how much source separation there is, etc. – In our calculations we used 4500 Btu/lb. From experience on rainy days it appears that wet household waste takes as many Btu's to evaporate the water as they contain. The rest of the time, we think it could be as high as 5000 Btu/lb.

4 Solid Tires on the front end loaders is the only way to go. One of the skid-steer tractors came with pneumatic tires. They were tried and abandoned.

5 Our layout expected the ash to be dropped directly into a truck that would deliver it to a landfill. The design failed, and space allowed no other option but to use containers. We finalized on three yard containers because of the weight of the wet ash. This change also meant less of some of the tipping floor space to the ash storage.

6 Since St. John's has been burning primarily household wastes rather than what is typically defined as Solid Waste, we have found a large amount of non-combustibles to be present. There has been good burn out; some observers state that it is as good as any they have seen anywhere. But about 20% of the original volume has remained for landfilling.

Start-up Costs

The fiscal year at St. John's is July 1 to June 30. Financial information available is linked to that time frame. Startup records began November 20, thus the data is for November 20, 1981 to June 30, 1982. Startup costs were excessive in the following areas:

1 Supplementary fuel costs of $81,828 were way beyond what it will be in the future when the Solid Waste Boiler will be able to function at capacity and at recommended temperatures.
2 Ash removal cost $20,453. This sum will decrease proportionately, even if nothing else changes, because of local arrangements. If the ash tests out the way we hope, it should cost considerably less.
3 Tipping fees were $32,633, which is lower than anticipated. The haulers in the area are used to tipping fees per yard and their compactor trucks have been found on the average, to compact one ton in 2.4 yards. Fees are being adjusted.
4 No additional electricity was generated in the first year, however, this will become a factor in the future.
5 None of the campus wastes were hauled by our own staff. This is now underway and it should add about $10,000 a year to revenues.
6 On the other hand, the equipment being in R&D, there were few maintenance costs which St. John's absorbed.

Financially, the plant was unable to make payments on its federal loan from proceeds. In addition, production lagged behind projections by $33,132. Since the construction costs had come in under the final authorized budget, this coverage plus the repayments were charged to construction/startup. Construction costs to us are $2,544,639 as compared to the budget of $2,545,949.

Steam Production Data

During the fiscal year the incinerator was in operation 130 of 365 days. Since November 20 it operated 130 of 223 possible days or 58.3% of the possible time. – During that same period of time the machine produced 24,834,940 lbs. of the total 113,325,510 lbs. of steam consumed, or 21.9%.

During the March 1 to March 7, 1982 test the average amount of waste burned per day was 44.3 tons. Since the 3000M is rated at 24,000,000 Btu/hour, if solid waste were to average 4500 Btu/lb., it would equate to 64 tons/day; if it averaged 5000 Btu/lb., it would be 57 tons/day.

Conclusion

After one year of R&D, the St. John's Solid Waste Boiler has moved methodically closer and closer to its ratings and to our expectations. BASIC's R&D is essentially completed on the moving floors, ash pit, ash removal, cupola caps, ram, I.D. fan. We expect further R&D in the areas of air seals, temperature stabilization and clinker avoidance.

St. John's R&D on the steam delivery problem and the rerouting of gases to the tall stack should be completed in the near future.

Preliminary air quality testing is scheduled for November 19, 1982. It is expected that more R&D will result from these findings. If test results show that a collector is required, BASIC will provide the device and, according to contract, install it. That installation will mark the conclusion of the major R&D by BASIC at St. John's. From that point on St. John's will totally take over the operation. But R&D will always be a part of our thought and function.

Appendix
St. John's University Resource Recovery Facility

Who

Saint John's University, Collegeville, MN 56321
Collegeville Township
Stearns County
Minnesota Pollution Control Agency
Minnesota Planning Office
U.S. Department of Housing and Urban Development
U.S. Department of Education

What

Resource Recovery Facility – Solid waste to steam; steam to heat & electricity.
Basic Environmental Engineering, Inc. Solid Waste Boiler Model 3000M.
Deltak Corporation Dina Boiler Model 1152R, Radiant Section Boiler and Economizer.
Pfeifer & Shultz/HDR conducted the feasibility study, engineered the layout, the building and the integration of this equipment into the existing plant.
Collegeville Township Building Permit
Stearns County License to operate a Modular Combustion Unit, disposing of about 64 tons per day of the county's municipal solid wastes.
MPCA Construction permit for Solid Waste Incinerator without additional pollution abatement equipment unless the unit fails to pass Minnesota Air Quality Standards. APC 14 applies to this project.
HUD Loan to finance this energy saving College Housing Project, 3%, 40 year loan totalling $1,255,500 for this project.
This sixth boiler for the St. John's Power Plant will be located in line with the other boilers, immediately to the south. The large tipping floor (70' x 90') will be located west of the plant. Steam output will, in large part, fill the demand of University housing and dining services. It has been sized for economic feasibility.
Additional electricity will be generated with what would otherwise be excess steam. A condensor is included to make this possible.
Authorized level of expenditure is $2,545,500.

Ratings:
Incinerator requires 24,000,000 BTU/hour.
Boiler produces 16,830#/hour of saturated steam at pressure of 175# psi. Rated efficiency 70.8%. Theoretically it could produce 95,802,000#/year of the total demand. Economic feasibility was established at the 73,358,000#/year level of useable steam.
Continuous operation: 24 hours/day, 7 days/week, shutting down periodically for preventive maintenance.
At the frequently quoted average of 4500 BTU/pound, this unit will consume 64 Ton/day; or 19,968 Ton/year of solid waste.

Where

Adjoining the existing power plant to the south and to the west.

When

St. John's University began the study in 1975.
Pfeifer & Schultz/HDR were contacted for the feasibility study early in 1977; final version of the Feasibility Study was issued March, 1979.
HUD Loan authorized Sept. 29, 1977 and Oct. 11, 1978; finalized Sept. 27, 1979.
St. John's University final decision, March 13, 1979.
Stearns County License dated May 1, 1979.
Pfeifer & Shultz/HDR contract for planning and implementing, May 18, 1979.
Collegeville Township Permit dated May 29, 1979.
BASIC contract dated August 31, 1979.
MPCA Construction Permit dated April 11, 1980.
Fabrication of equipment started April, 1980.
Building Construction began in November, 1980.
Installation of Solid Waste Boiler completed in April, 1981.
Construction completed November, 1981.
Research and Development begun November, 1981.

Why

Economics – The variables associated with the cost of fuel and the supply of fuel led St. John's to consider this plentiful and cheapest of fuels; reduce on-campus refuse pickup costs; provide savings for investment in other energy projects.
Energy conservation – make use of the BTU's in solid waste; encourage source separation of recyclables; small is beautiful, and is the only way to approach a solution to the solid wastes problems of non-metro/urban areas.
Environment – Avoid multiplying landfills; produce sanitary substance for landfilling; provide cleaner air through reduced particulate.
Service to County – Solid wastes are a responsibility of the county in Minnesota. Assist in solving current disposal problems facing the county and become a long term contributor to the county's plan for handling solid wastes by building this plant at no cost to the citizens.

Long run cheaper service to the citizens of the areas to be served.

Educational – Raise the level of energy consciousness in the populace; give, in action, our position on the use of resources and the importance of recycling.

Why at St. John's? – The University already has a central plant with co-generation capability and multiple use for the steam including district heating. Consequently this is a year-round market. All that is required to make use of this system with the steam from this plant is a single connection to the main steam header.

Research – Pilot project to provide information and service to many municipalities and corporations in the state and region.

How

Source – Contracts will be drawn with the private and municipal haulers, who are licensed by the county, to dispose of the wastes they handle at the St. John's facility. In conjunction with the County Planning Office, develop and maintain the method for smoothing the arrival of wastes at the St. John's plant to match its needs. It is estimated that 10-12 compactor trucks per day will unload at the plant, six days per week. There will thus be a reduction in the number of trucks hauling coal.

Process – The compactor truck drives into the building; dumps its load on the cement tipping floor; all solid wastes will be stored inside the building awaiting use as fuel, turn over period will be up to 36 hours; storage areas within the building will be rotated for thorough cleaning.

The operator with a front end loader pushes the solid waste into a convenient temporary storage position; some separation of wastes will be accomplished by the operator, who will shove aside things that to do not belong in the incinerator (e.g. demolition waste, heavy metal items, concentrations of paint, sealed drums, etc.); the tipping floor will be arranged for easy daily removal of such items, as well as for easy removal of all wastes in case of a major breakdown.

The operator keeps the charging chamber at the automatic loading ram full; incinerator calls for fuel as required and ram charges first chamber spreading the charge across the firebox; with controlled air intake many of the hydrocarbons are carried off unburned in gaseous form; in the afterburner these are fully combusted leaving an odorless almost clear exhaust that is in compliance with MPCA regulations; the gas enters the convection boiler at temperatures of 1500° to 1800°F and exits at about 400°F; high pressure steam is produced to run turbines, heat buildings, etc.; the exhaust exits through the stack.

Within the incinerator the non-combustibles, non volatile carbons and other residuals sift slowly downward and toward the rear as a result of the action of the moving floor; resident time is estimated to be two hours; at the rear the ash falls into a water quench, settling to the bottom and rear of the tank; the ash removal arm carries it from the tank to a storage bin awaiting removal from the building; ash will be desposited at a sanitary landfill, unless testing and MPCA allows other disposal.

Technology – Stoichiometric air in the first and main burn chamber. Air inflow is automatically modulated to control and smooth the temperature and rate of burn. This is coupled with a radiant section water wall boiler which surrounds the chamber, further controlling the temperatures. This main combustion chamber is operated at very low uplift velocities to prevent fine ash particles from being entrained. The low velocity, together with the low operating temperatures in the main chamber, plus the built in afterburner enables the unit to operate very cleanly. Particulate tests run on the BASIC incinerators have ranged between 0.04 to 0.07 gr/scf corrected to 12% CO_2; carbon monoxide is less than 50 ppm; nitogren oxide is less than 50 ppm; hydrocarbon is less than 12 ppm. In normal operation opacity is anticipated to be within 0-5%, with brief excursions up to 15%. CO_2 formation to organic acid will not occur since a scrubber is not employed. No organic acid will occur as a result of incomplete combustion because of afterburner retention time at temperatures over 1500°F. Any Chlorine in the wastes will be liberated as Cl_2 gas rather than as HCl because of the controlled operating temperatures.

In addition it might be pointed out that all of the emissions just referred to will represent a reduction and/or equivalent offset for NOx, CO, Hydrocarbons and particulate, since this unit will replace steam previously produced by burning fossil fuel.

Odors? – The plant has been designed so all equipment other than the scale, is located within the building. This will protect the equipment from the weather; make it immediately available to personnel; contain the sounds of operation; contain the unsightly materials and their accompanying odors; establish a negative pressure within the building drawing air through the building into the combustion chamber and up the stack. In this way the environment around the plant should be uneffected.

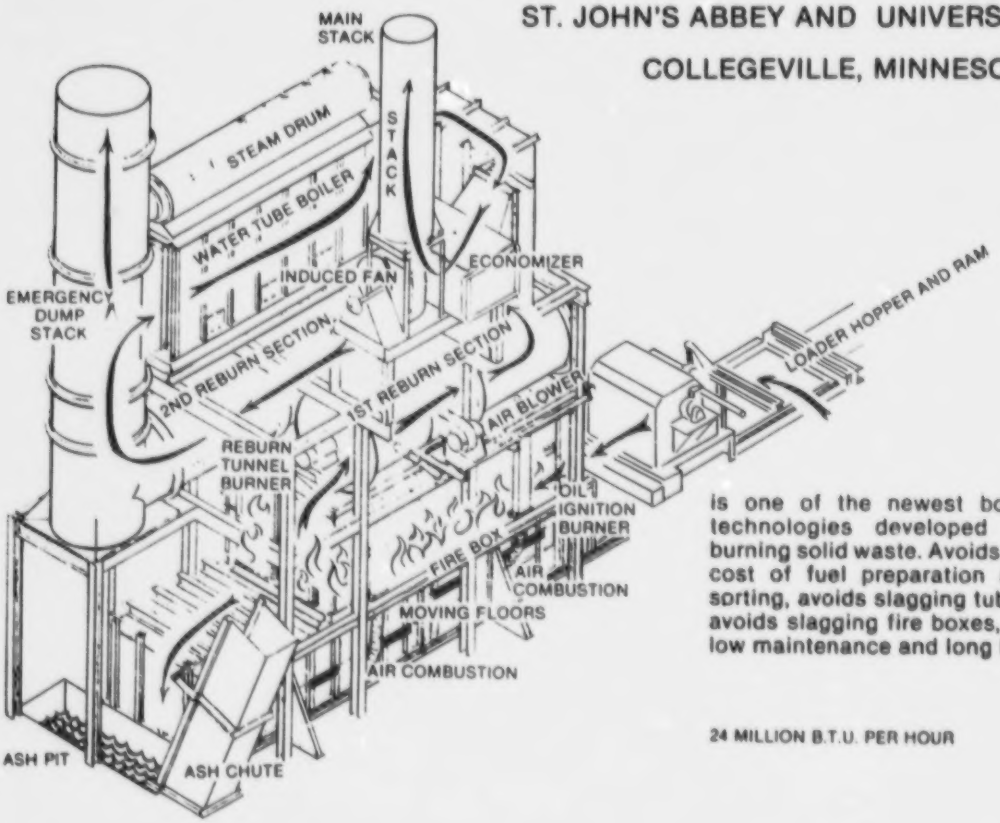
Repayment – Monies to repay the loan will be derived in four ways: a) from fuel b) by making use of additional electrical generation possibilities; c) from tipping fees; d) from savings in the disposal costs of university for its own refuse removal.

BASIC Solid Waste Boiler

figure 1

ST. JOHN'S ABBEY AND UNIVERSITY

COLLEGEVILLE, MINNESOTA



is one of the newest boiler technologies developed for burning solid waste. Avoids the cost of fuel preparation and sorting, avoids slagging tubes, avoids slagging fire boxes, for low maintenance and long life.

24 MILLION B.T.U. PER HOUR

Semi-Suspension Burning Operating Experience at Hamilton and Akron

by:
Joseph W. Kennedy P.Eng.
Director of Operations
Resource Recovery Projects
Tricil Limited

Abstract

The disposal of municipal solid waste (MSW) is a problem facing almost every urban area in the country. Today there is a growng conviction that as much as possible resources should be recovered and that garbage should be burned for energy. Landfill is no longer the only acceptable option.

There are a number of technologies used to recover energy from MSW. Semi-suspension burning of MSW is a viable technology. Similar technology has been used by North American industry to recover energy from a variety of solid wastes including; bark, wood waste, bagasse and coffee residue.

The Hamilton, Ontario SWARU plant and the Akron, Ohio Recycle Energy System, both operated by Tricil, demonstrate that the semi-suspension burning technology provides cost effective and reliable MSW disposal and material and energy recovery.

Introduction

The Hamilton SWARU plant processes between 400 and 500 tons per day of MSW. Ferrous metal is recovered and the majority of steam produced at the plant is used to generate electricity.

The Akron Recycle Energy System processes between 800 and 1000 tons per day of MSW. Ferrous metal is recovered. Electricity is generated for in-plant use and steam is sold to about 200 downtown customers including three hospitals, Akron University and B.F. Goodrich.

Semi-Suspension Burning Process

The semi-suspension burning process is both simple and flexible permitting the recovery of valuable materials before and after combustion and the recovery of energy. The basic principles of the semi-suspension burning process are:

1. The best economic use for the bulk of municipal solid waste is as a fuel in an energy recovery system.
2. The energy recovery system must be thermodynamically efficient.
3. Municipal solid waste requires some processing prior to combustion, just as coal requires pulverization and oil requires atomization, to achieve efficient combustion.
4. All stack gases and other plant emissions are free of odors and comply with appropriate environmental standards.
5. Material, such as metals, glass and uncontaminated paper can be recovered where economically feasible.

The main components of the semi-suspension burning process employed in the Hamilton SWARU plant and the Akron Recycle Energy System are shown in figure 1, schematic of Semi-Suspension Burning Process. The process consists of steel pan conveyors, shredders, belt conveyors, boiler feed system, spreader stoker boilers, continuous ash removal systems and air emission control equipment.

Municipal solid waste is coarsely shredded to a nominal size of 4 – 6 inches. Occasionally municipal solid waste contains items which may cause an explosion when processed or burned. Some design and operating features which are utilized to reduce the number and effect of the explosions are:

1. Presorting of potentially hazardous items from the receiving floor and from the in-feed conveyor to the shredder.
2. Coarse shredding of waste.
3. Venting to diffuse over-pressures.
4. Use of Fenwal explosion suppression system.
5. Circulation of air through hood of the shredder and shredder to avoid build-up of pockets of volatile gases.

6 Blast walls for protection against flames and projectiles.

The magnetic separator removes ferrous metal from the shredded refuse, prior to combustion to avoid oxidation and alloying. Approximately 4 – 5% of the waste received is recovered as ferrous metal.

The shredded refuse is easily transported by belt conveyors which are reliable and provide process flexibility to accommodate any future processing option.

The boiler feed system, incorporating fuel proportioners, controls the shredded refuse fuel feed to the boilers. The shredded refuse is uniformly distributed across the boiler through air-swept feeders. Approximately 20% of the total combustion air is overfire air (the majority of which comes through the feeders). The waste is dried and fired as it drops toward the grate at the bottom of the furnace. As a result of the semi-suspension burning process, the waterwall furnace requires no refractory whatsoever. Complete combustion with minimum excess air requirement and uniform high furnace temperatures is achieved by suspension firing with on-grate burning. The grate travels toward the front of the boiler against the direction of waste feed. The grate is relativley small and simple in design.

The refuse burns down to a depth to 4 to 6 inches of ash discharging from the front of the grate. Low grate temperatures are achieved so glass remains unmelted and clinkers and slag are not formed. Also, the amount of salts and metals that are volatilized is kept to a minimum.

The high quality, sterile, granular ash containing less than 1% by weight unburned carbon is produced from the combustion process. The ash is less than 4% by volume of the waste received. The bottom ash, grate siftings and cinders are discharged into a quench tank which provides continuous, automatic ash removal.

Reducing atmospheric conditions do not exist within the boiler. Corrosion is therefore well within acceptable limits, even at high metal temperatures.

Hamilton Plant Experience

Construction of the Hamilton plant (figure 2) began in 1970 and the plant went into its operational phase in the fall of 1972. The design capacity of 600 tons per day and capital costs was $9,000,000, which included land purchase and engineering costs. The funding for the plant was obtained through a municipal debenture and its on-going operation is supported through the municipal tax base.

In February 1978, the Region of Hamilton-Wentworth and Tricil Limited entered into a ten year full service contract.

As the waste management contractor for the Region, Tricil has designed, constructed and now operates a complete waste management program. It focuses on five services:

1 The operation of the Hamilton SWARU plant, modified by Tricil.

2 Installation and operation of a turbine-generator to produce electricity.

3 The operation of three transfer stations.

4 The operation of a bulk handling system.

5 The operation of a landfill site.

Under the terms of the full service contract, Tricil has upgraded the Hamilton plant to provide more than twice its previous operating capacity.

Since Tricil's takeover in February 1978, a modification program involving both operating changes and technical improvements has been successfully completed. The modification program included:

1 Improvement to refuse and ash flow through the process to prevent jamming, bridging or plugging.

2 Improvement of combustion to upgrade the quality of the ash to reduce emissions.

3 Improvement of the general effectiveness of the plant to reduce labour and to increase productivity.

The Hamilton SWARU plant has always been an example of Canadian innovation in the solid waste industry. It is now the second plant in North America which generates electricity from MSW for sale to a utility grid system. Under a Tricil/Ontario Energy Corporation joint venture, a 4 megawatt turbine-generator (figure 3) generates electricity for sale to Ontario Hydro.

The Akron Recycle Energy System Experience

During the 1970's the City of Akron, Ohio decided to build a modern North American energy recovery plant using North American technology to dispose of municipal solid waste and supply steam to the City's downtown area. The Akron Recycle Energy System (RES) was commissioned in 1979, and financed through the Ohio Water Development Authority (O.W.D.A.), the City and Summit County, (figure 4).

The energy recovery facility experienced difficulty during the start-up phase and after two years the plant's performance was still well below its design capacity. During this period, design changes were made at the plant and substantial capital was expended. The capital invested and changes required escalated to the point where a decision had to be made whether to radically modify the plant or close it down.

The City and O.W.D.A. reviewed a number of alternatives and finally selected an approach which would require that any future modification would be guaranteed successful by the selected contractor. Tricil Resources, Inc., a subsidiary of Tricil Limited was selected as contractor.

In June 1981, Tricil signed an agreement with the City of Akron, the Ohio Citizens Bank, and the O.W.D.A. to undertake the modification and operation of the Akron RES. Under this agreement, Tricil modified the RES to reliably process at least 800 tons per day of municipal solid waste for a fixed price of $11,450,000.

Some highlights of the modification program include:

1. The replacement of the original pneumatic handling systems with conveyor belt systems to ensure reliable transport of materials throughout the plant.
2. The installation of a Tricil-design boiler feed system to provide a controlled flow of prepared refuse to the boiler.
3. The installation of a Tricil-design wet ash removal system to safely provide continuous removal of residues from the boilers and optimize the operating conditions in the boilers to improve combustion and maximize the generation of steam.
4. The replacement of the original pneumatic control system with a microprocesser based distributed control system.
5. A program to improve the general operating practices throughout the plant.

To improve the co-generation capability of the plant, the City of Akron has contracted with Tricil to install a hot water distribution system. A chilled water distribution system is now being developed to improve summer loading.

In April 1982, Tricil entered into a 10 year long term operating service agreement to operate the RES and its steam distribution system.

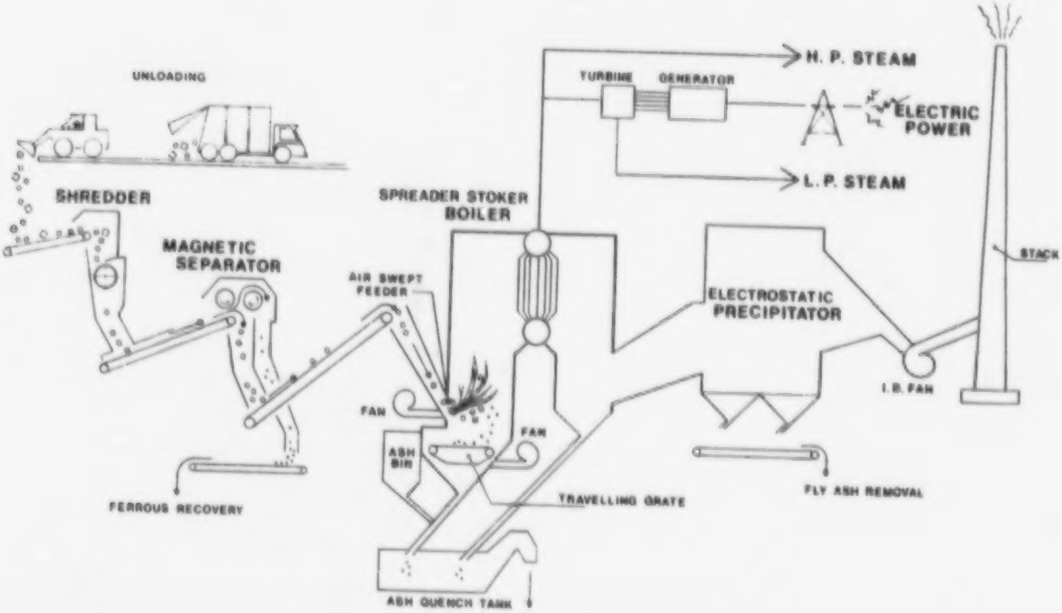
The modification and operation programs provide a reliable system of North American tehnology for disposing of MSW and generating saleable energy.

Conclusion

Semi-suspension burning technology is successfully demonstrated at the Hamilton SWARU plant and the Akron Recycle Energy System. Innovative energy management programs have been inplemented at both plants. The Full Service Contract approach is being used for the modification and operation of the plants. Single source responsibility for performance and long term operating costs provide an attractive alternative to conventional methods of procuring energy from waste processes and disposal services.

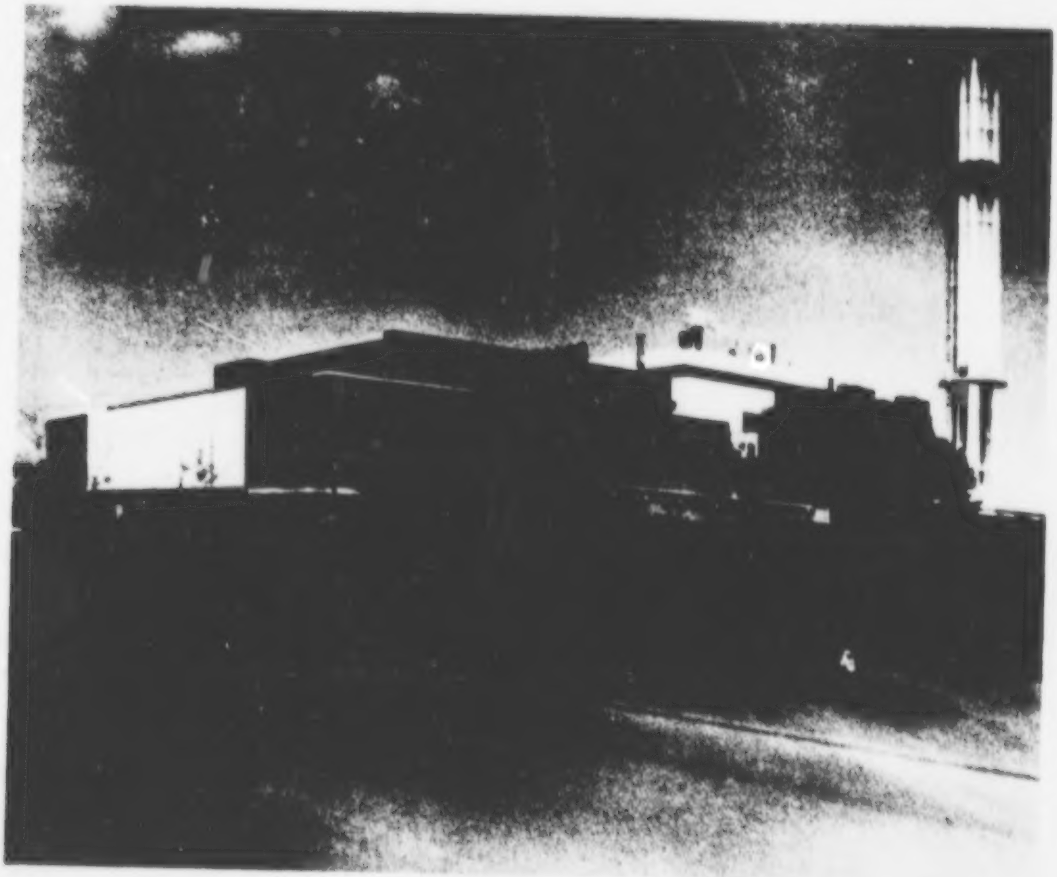
Schematic, Semi-Suspension Burning Process

figure 1



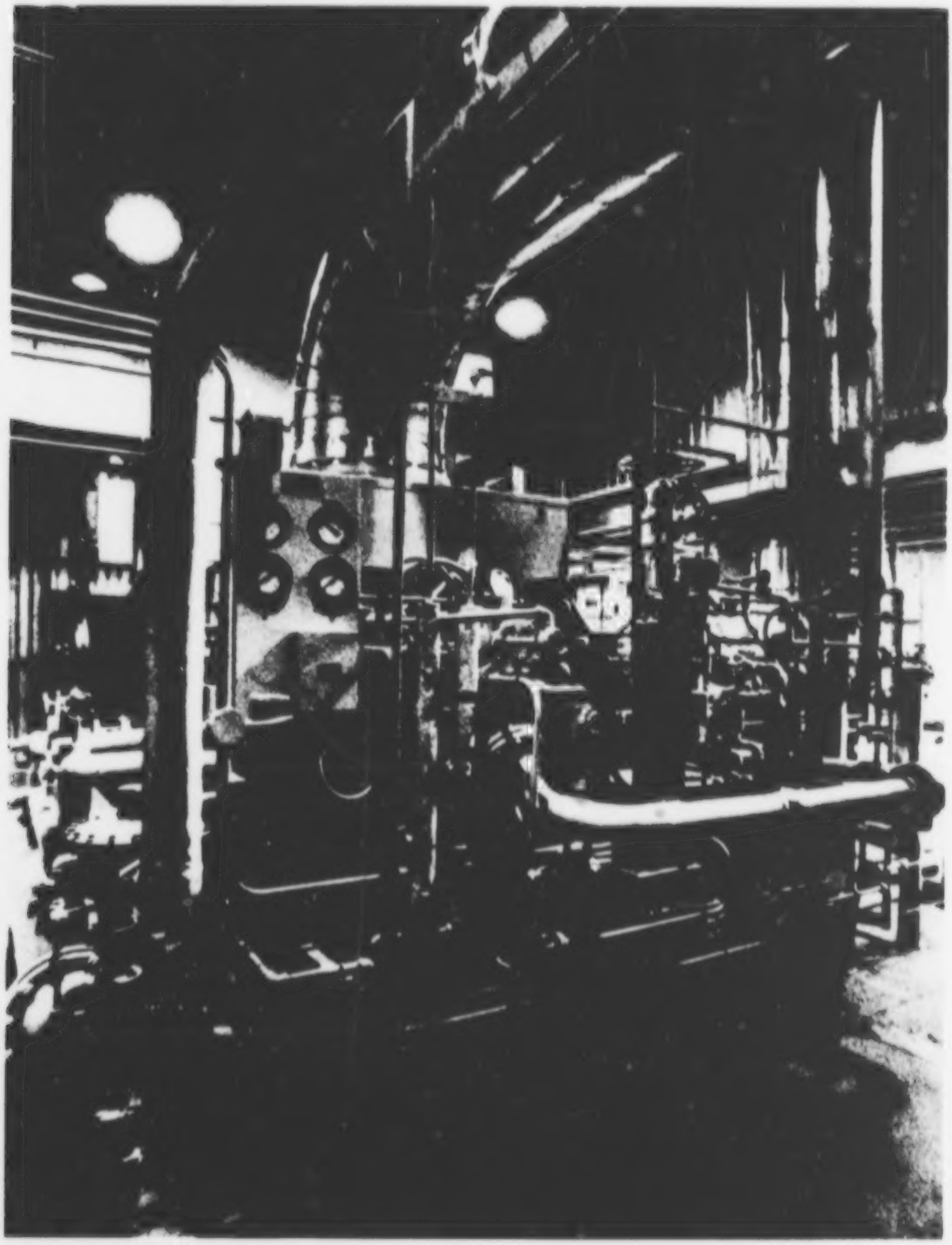
Hamilton SWARU Plant

figure 2



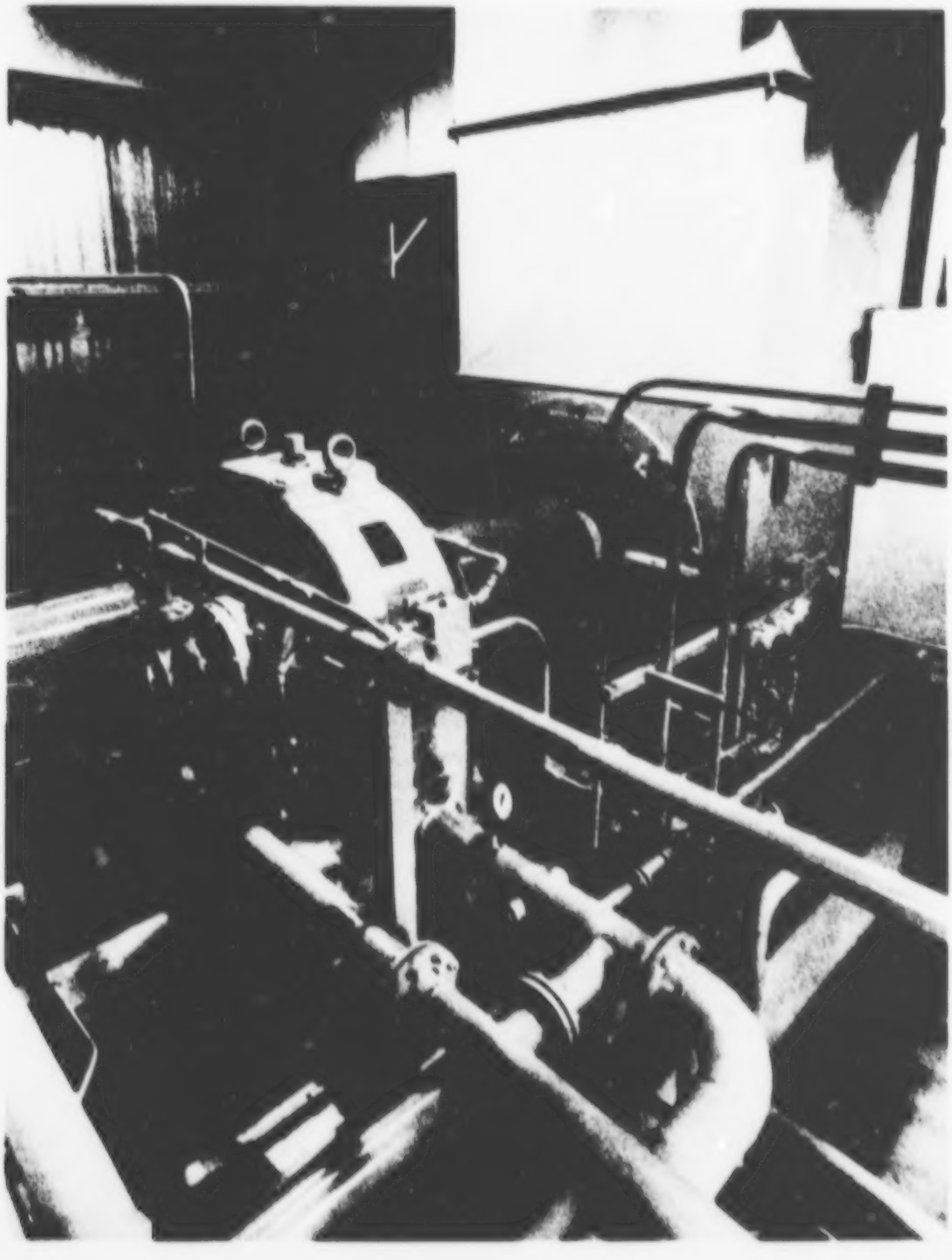
Turbine-Generator, Hamilton SWARU Plant

figure 3



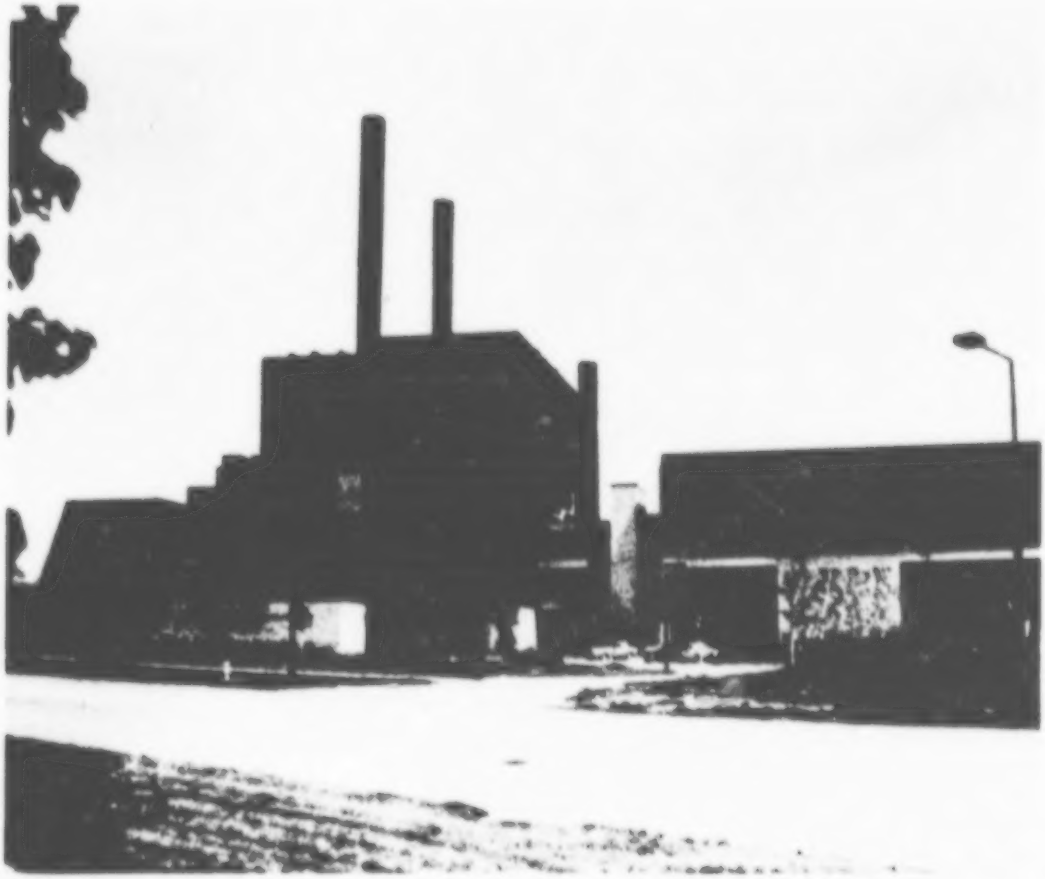
Turbine-Generator, Hamilton SWARU Plant

figure 3



Akron Recycle Energy System Plant

figure 4



Operating Experience at Quebec Metro Incinerator

by:
Hervé Aubin
Quebec Urban Community

and

Michel Roux
Montenay Inc.

Abstract

The Québec Metro Incinerator was started during April 1974 and in the middle of 1975 all four units rated at 250 sh. tons/day have been operational.

The main scope of this paper is to give a survey on facts and data which were compiled by us during the last 8 years. Emphasis is made on how we solved the various problems encountered. We also present comparisons between the real performance of the plant and what was expected at the design period.

Introduction

Since 1970, the city of Québec and the 12 member-municipalities which surround it have been grouped together in an organization known as the Communauté urbaine de Québec (Québec Urban Community), which coordinates and manages a number of services of a regional nature. It is an organization similar to the Metro Toronto government. It covers an area of 550 square kilometres and has a population of 480,000 inhabitants.

One of the responsibilities of the CUQ is the elimination of solid waste (garbage), and the method, chosen in 1971, is incineration with the production of heat (steam). This choice was made after a long study and the signature of a long-term contract with Anglo Canadian Pulp and Paper, today Reed Paper, providing for delivery to the paper mill of all the steam produced by the incinerator.

The Québec Metro Incinerator was built between 1972 and 1975. The first tons of garbage arrived at the plant in April 1974, and by the middle of 1975 the entire plant became operational.

We plan, in this text, to describe briefly the plant and its operation, and to relate some of the principal experiences we have gone through during the past 8 years.

Description

The Québec Metro Incinerator has a nominal capacity of 907 metric tons (1000 short tons) per day and includes 4 Von Roll furnaces, each one integrated with a Dominion Bridge boiler. Figure 2 shows a cut-away view of the plant, and in particular the furnace-boiler unit.

The main operational characteristics of each unit are as follows:

Rated burning capacity: 9,5 m.t./h (10,4 sh.t./h)
Refuse H.H.V.: 13 955 kj/kg (6000 BTU/lb)
Steam production: 36,8 m.t./h (81,000 BTU/h)
Feed water temperature: 142°C (287°F)
Steam pressure at boiler discharge: 4689 kPa (680 psig)
Steam temperature: 315°C (600°F)
Combustion air temperature: 15°C (60°F)
Gas temperature at boiler outlet: 250°C (480°F)

Design features of the incineration train are:

1. From the storage pit, the refuse is uniformly fed to the stoker through a feeding vibrator and a water cooled chute, a system which gives excellent results.
2. The stoker is composed of three separated grates inclined at 15° and independently driven. The speed of each grate, as well as the combustion air distribution can be controlled to ensure a satisfactory combustion.
3. The combustion chamber above the fire-bed is formed with conventional paned-type water walls.

   Since standing bunker "C" oil burners are provided on three units, there is a special water-wall lined combustion chamber in the upper part of the radiation section of the furnace.
4. The boiler is built with all the tubes panels hung up vertically and perpendicular to the gas flow

and with only one drum (the steam drum). For tubes cleaning, we use a mechanical rapping system instead of soot blowers.

5 At the outlet of each boiler, there is an electrostatic precipitator.

6 As you can see on figure 3, residue and fly ash are separately handled. Moved from the quenching trough by a drag conveyor, the residue is carried over an incline to a storage pit. Fly ash coming from the economizer section of the boiler and from the precipitator is moved by a chain conveyor to a silo.

7 To provide compensation between the fluctuating steam production of the boilers and the steady steam sent out, there is a feed water accumulator coupled with the deaerator.

Facts and Data

As we have already indicated, the plant was partially in operation in April 1974 and was completed during the year 1975. Since then, it has operated almost without interruption. We have burned more than 1,600,000 metric tons of garbage in it and we have delivered more than 2,900,000 metric tons of steam to the paper mill. However, this does not mean that the past 8 years have been without incident.

Operation

The CUQ itself operated the plant up until October 1, 1979, with a team which it put together to manage, operate and maintain it. This required a great deal of effort since such "incineration plants" are somewhat rare in Canada. On that date, the CUQ turned the plant over to a private firm, Montenay Canada Ltd, which absorbed the personnel and undertook to operate and maintain the plant as if it owned it, until 1994.

After 3 years working with this system, the CUQ is satisfied and has no wish to go back. A recent study showed that the plant is being well managed and maintained. On the other hand, such an incineration plant is a real industrial plant and there is no doubt that the laws governing municipal administrations, at least in Québec, do complicate the daily management of it. Therefore, it is better to turn over the entire operation to private enterprise.

Quantity of Refuse

On examining figure 4, we find that the reality is far from the forecasts made in 1971 for the annual progression of the population of the region and the quantity of refuse to be burned.

The amount of garbage received at the plant has never surpassed 217 000 metric tons, and it is presently at a ceiling of 200 000 tons and is tending to diminish.

This state of affairs has considerably altered our forecasted revenues and has forced us to increase the tipping fee according to the rate of inflation and this in spite of the fact that the sale price of the steam increased in the same proportion as that of bunker "C".

This situation, which of course is not peculiar to our region, naturally causes us some headaches because we were counting on a regular increase in the quantity of refuse in order to stabilize our net operating costs. Presently, the plant is under-exploited. We could easily burn 40 000 tons more annually without any appreciable increase in costs. We therefore are looking for substitutes and it is possible that we will soon be able to count on a certain quantity of wood residues from a large sawmill in the region.

Steam Production

We are currently producing an average of 2.7 tons of steam per ton of refuse and we deliver 2.2 tons to Reed Paper.

Taking into account the efficiency of our installations, and the composition and heat value of the refuse, we are satisfied with the results considering that prior to 1979 the amount of steam sold was less than 1.9 tons per ton of refuse burned. Furthermore, we believe that it is not possible to surpass a production of 3.0 tons of steam per ton of refuse burned.

The main problem we are faced with is that of the irregularity of the flow of steam delivered to our client. A clause in the contract specifies that the variation in the flow must not exceed 7%, and it is not possible for us to always respect this clause except under normal conditions of operation when it is sufficient to have control over the primary and secondary air intake and the speed of the grates.

Moreover, the accumulator is a help because it can absorb increases in the flow up to 40%. Unfortunately, it cannot compensate as efficiently for decreases in the flow. Also, the fuel we use is unpredictable and, in addition, we are subject to mechanical breakdowns, especially in the residue conveyors. Thus, the variations in the steam flow to our client are almost always decreases and often large decreases, which of course does not help him at all, especially during the winter season when his mill is operating at close to full capacity.

The situation is such that, in order to renew his confidence, we are preparing to build an auxiliary boiler fired by oil or natural gas, whose instant and dependable start-up will allow us to respect our contract at all times.

Air Pollution Control

A good combustion of the refuse and an adequate purification of the fumes by electrofilters require constant control of the primary and secondary air intakes, a judicious injection of that air and conditions favourable to a good air-fuel mixture in the combustion chamber.

Because it is difficult to regulate perfectly the admission and distribution of the refuse on the main grate and also because the heat value of the fuel varies constantly, there exists a certain incompatibility between the steady production of steam and a good combustion of the refuse.

We quickly learned that if we wanted to satisfy our client, we were obliged to increase the load of refuse on the main grate and to blow a large quantity of air through that mass of refuse. As a result, we obtained a fairly constant production of steam but the paper was only partially burned, which meant the flow of a considerable quantity of half-burned paper particles towards the boiler and the precipitator. The boiler quickly became carbonized, the electrofilter was overcharged when it was fed too much gas to purify, and as a result we greatly surpassed the norm set by the Ministry of the Environment for the emission into the atmosphere of particulate matter, that is 270 milligrams per cubic metre of dry gas corrected to 12% CO_2 at 25°C and at a pressure of 100,9 kPa. Naturally, we received frequent complaints from residents of the surrounding area.

At the end of 1977, we gave a mandate to Shawinigan Engineering to study the problem and to recommend measures to correct this situation.

Following this study, in 1979, and 1980 we proceeded with the following modifications to the inside of the four furnaces (figure 5):

1 Construction of a water-cooled vault above the main grate;

2 The installation of a screen wall above the finishing grate;

3 Relocalization and redistribution of the secondary air intakes.

The first two measures were aimed at creating a double combustion chamber in order to retain the air-fuel mixture at the desired temperature during a sufficiently long period so that the carbon in suspension could be burned as completely as possible.

The third measure was aimed at improving the regulation of the air supply and thus lower the amount of excess air in the gases.

Thanks to the modifications and to steady efforts to control the admission of refuse and excess air in the gases, we have since succeeded in conforming to the norms of the Ministry. The results of the last official sampling show an average particulate emission equal to 58 milligrams per cubic metre of gas.

Fly Ash and Residues

Since the plant went into operation, we have discovered that the system of transporting and storing fly ash was a source of problems, and particularly created a problem of maintenance and cleanliness, part of it being dispersed in the building. In addition, fly ash had a tendency to collect in the bridging, which made its removal very difficult.

Not having found an outlet for this by-product, we gradually modified the installation, at first by experimenting with, but without much success, a system of transporting the fly ash by water towards the ash pit rather than to the silo.

Today, the fly ash is transported dry towards the clinker trough by chain conveyors enclosed in a perfectly air-tight Redler. A system of water injection prevents the fly ash from staying on the surface of the water.

The evacuation of ash and clinkers to the pit is carried out by two conveyors. One of them, the "Ridling Conveyor", being the cause of frequent stops in the furnaces because of breakdowns, we are now trying to eliminate it.

From the pit, the residues are taken by a crane to be loaded into a truck and transported to a sanitary landfill. The operator of this site has perfected a system of recuperating the metallic portion which is then disposed of on the scrap metal market. As far as the remaining portion is concerned, we are studying the possibility of the municipalities using it for road beds.

The quantity of residues removed from the plant is equal to about 30% of the weight of the refuse burned and the metallic portion recuperated corresponds to some 13% of the weight of the residues. The revenues coming from this recuperation are therefore not very great, especially during the current crisis in the economy.

Boilers

The tubes in our boilers are cleaned of soot by a mechanical rapping system. In effect, rapping the base of the tubes in a predetermined cycle allows us to knock off the deposits of soot which surround them.

We have discovered that this system of cleaning is not the one which gives the best results, though it is better than the system of steam blowers. The shock waves are too weak to clean the tube along its entire length.

To complete the cleaning of our boilers, we must periodically wash out the tubes by the projection of water at high pressure. This is not easy to do, the points of access being limited, and it could be the cause of damage to the radiation section of the furnace when humidity infiltrates all over.

In our opinion, the cleaning system which would have given the best results up to now, is that of air blowers coupled with moveable ramps. It in effect allows us to reach all tubes and can be applied to their entire surface.

The tubes which make up the different sections of the boilers are, according to their position in the passage of the gases, more or less subject to accelerated deterioration. The tubes which form the main combustion chamber (upper furnace walls) are, along a good part of their length, protected from erosion and corrosion by a plastic refractory. Three years ago, we were obliged to increase the protected surface after having found damage on some tubes just above the refractory put in place during construction of the furnaces.

The evaporation zones I and II are generally the most delicate and suffer much more from the effects of erosion than from corrosion and that, on the surface of the tubes used for the rapid passage of combustion gases.

On each boiler, we were obliged to replace several rows of tubes on evaporator I and evaporator II after an average of 28 000 hours of operation. Their walls had become too thin. It was then that we found that this wearing down process took place outside and was due to erosion and not corrosion. As far as the inside surface is concerned, we find it intact, which indicates that our system of purification of the feed water is very satisfactory. It is a system of demineralization through the exchange of ions to which was added a condensate polisher since our client returns to us 50% of the steam in the form of condensate at a temperature of 77°C (170°F).

Conclusion

There are several other experiences that we could tell you about. However, we believe that the preceding is enough to show that the operation of such a plant is a complex operation, especially when we must pursue two objectives which are to some extent incompatible, on the one hand to burn municipal garbage and, on the other hand, to supply a client with a continuous and steady flow of steam. These efforts, however, have their justification in the fact that the energy thus recuperated and used equals some 32 million litres (200 000 barrels) of oil annually that we do not have to import.

The direct revenues that the sale of this energy brings to the region are considerable since they cover an important part of our costs of operation (figure 6).

The apparent cost of garbage incineration is without doubt higher than that of burying it in the ground. However, it is not certain that this holds true if we take into account the consequences of burying the refuse, that is the total loss of recuperable materials and energy, the impossibility of using the burial site for many years and the potential damage to the environment and the underground waterways.

Acknowledgements

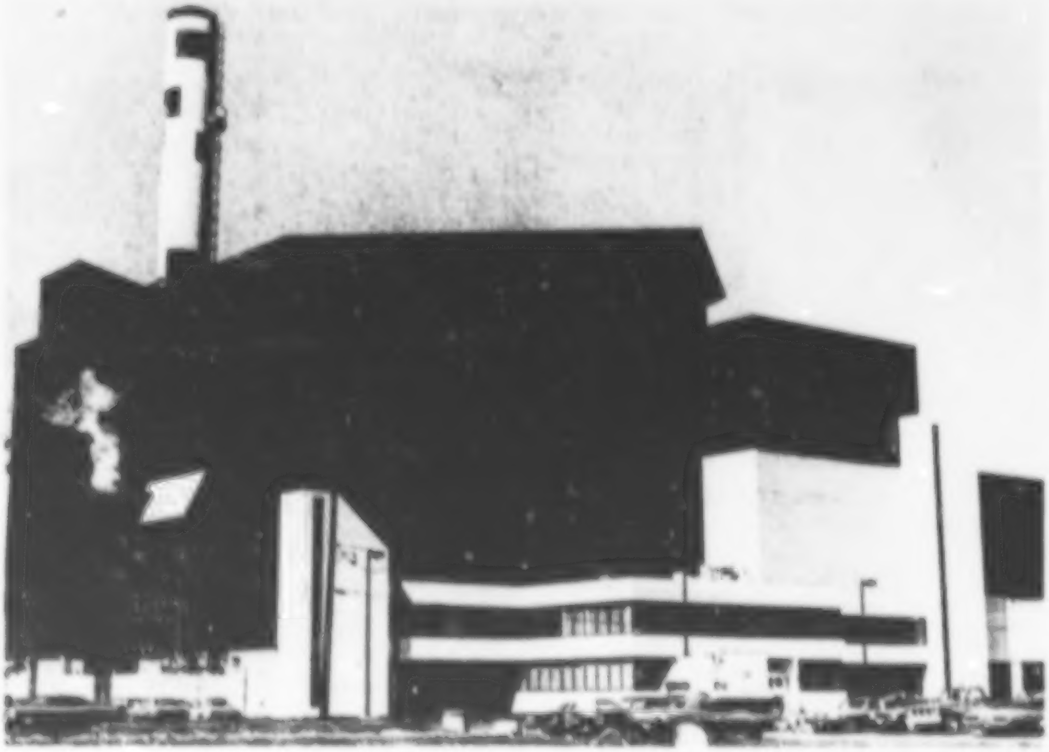
The authors wish to express their thanks to Messrs Roland Rinfret of Montenay Canada Ltd and Ken Stewart of QUC for their assistance.

Reference:

1 AUBIN H. "The New Quebec Metro Incinerator" **Proceedings of 1974 National Incinerator Conference ASME**, Miami, Florida, May 12 – 15, 1974, pp. 203-212

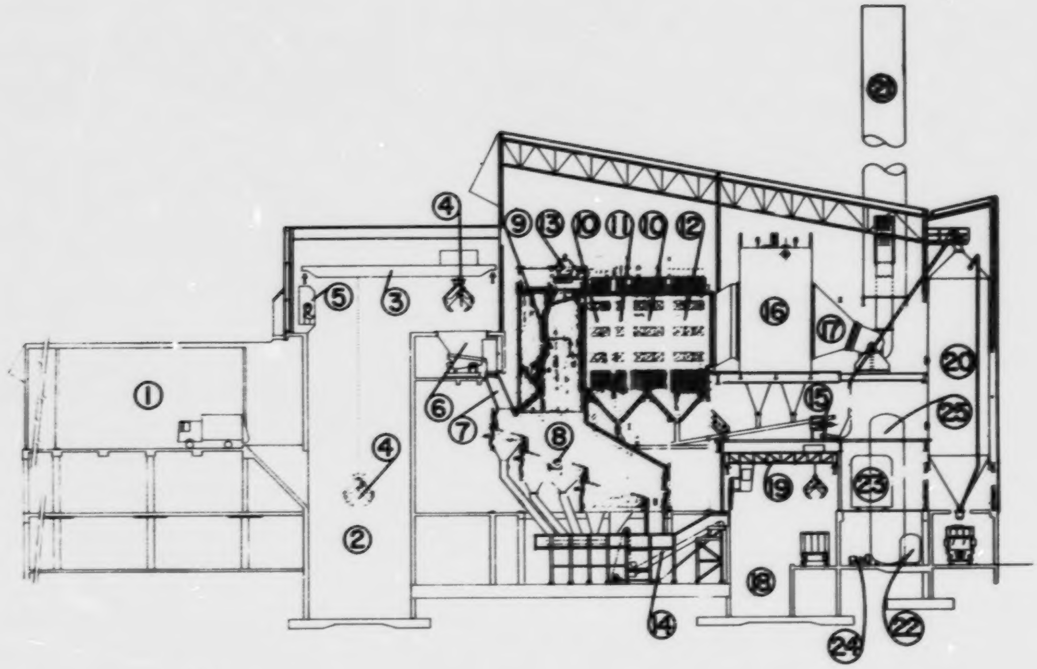
The Quebec Incinerator

figure 1



Cut-away view of the Quebec Plant

figure 2

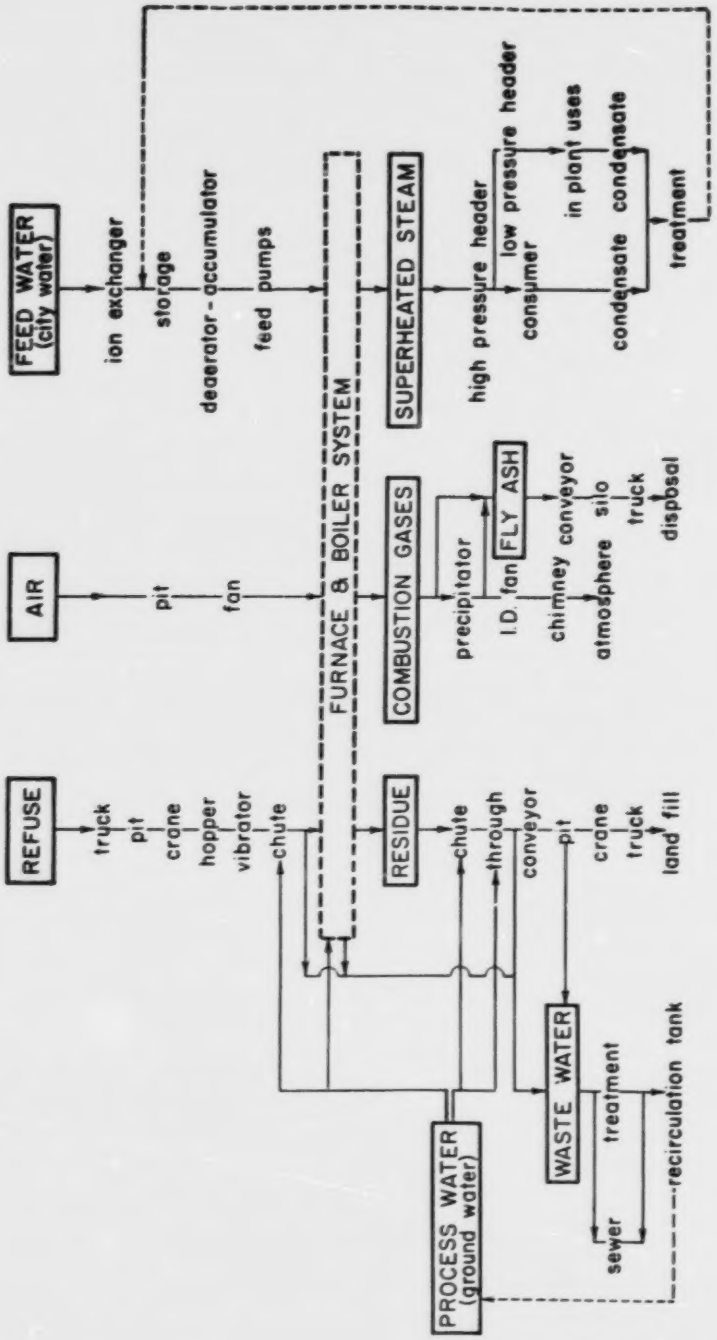


LEGEND

1 Unloading platform
2 Refuse pit
3 Travelling crane
4 Bucket
5 Crane operator's cabin
6 Feeding hopper and vibrator
7 Feeding chute
8 Grates
9 Radiation zone
10 Convection zone
11 Superheater
12 Economizer
13 Steam drum
14 Residue conveyor
15 Fly ash conveyor
16 Electrostatic precipitator
17 Induced draft fan
18 Residue pit
19 Travelling crane
20 Fly ash silo
21 Chimney
22 Feed water treatment
23 Make up tank
24 Feed pump
25 Deaerator-accumulator

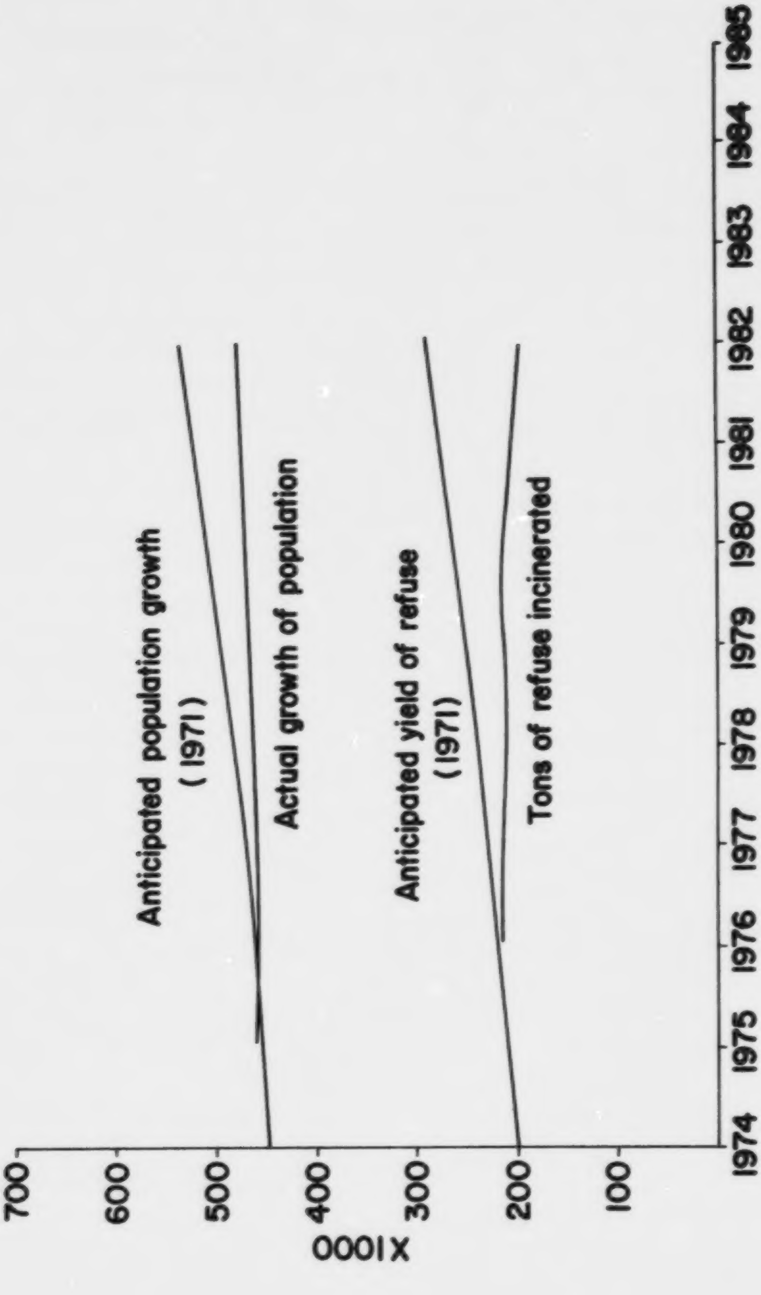
Flow-diagram – Quebec Incinerator Plant

figure 3



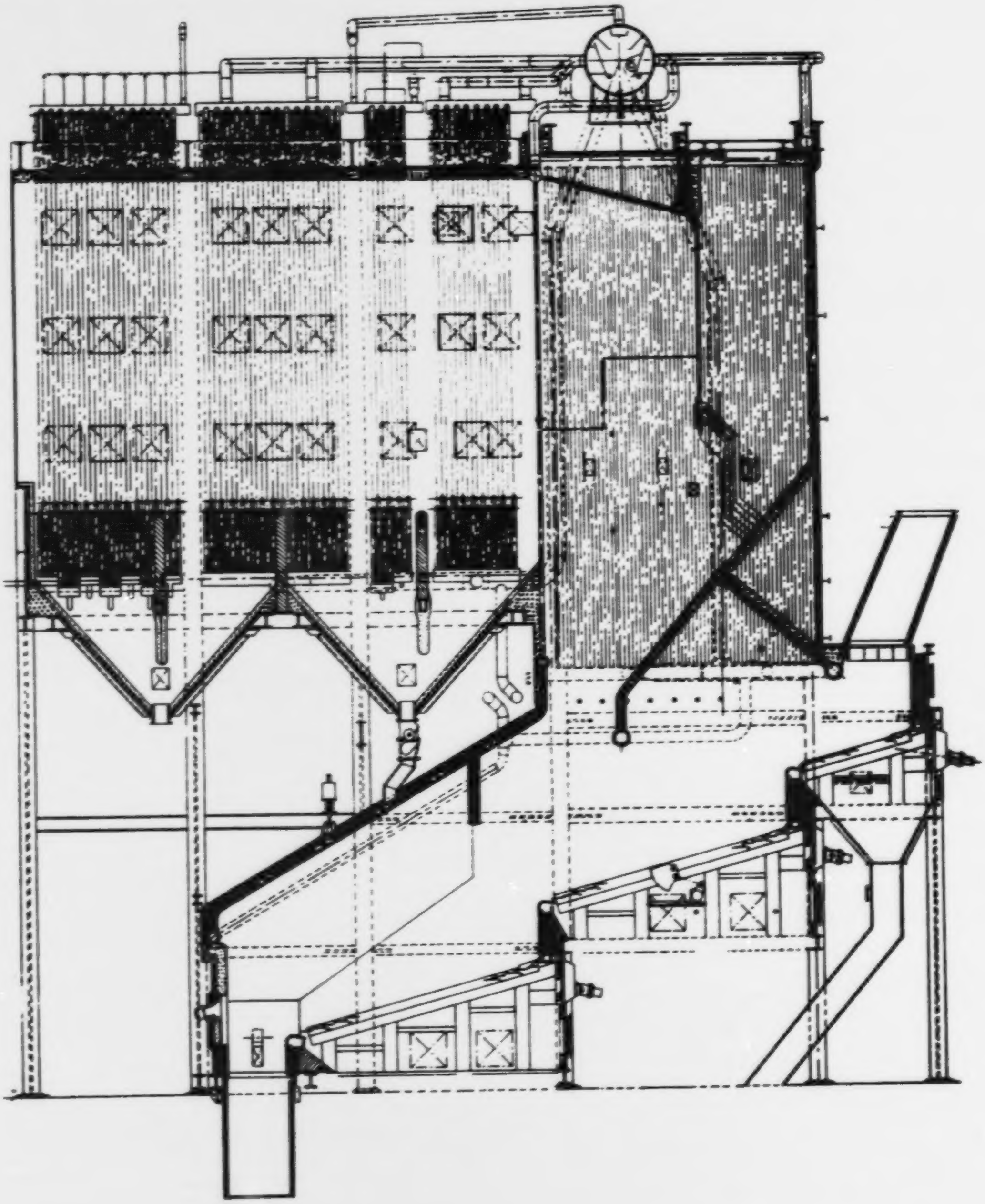
Population growth and yield of refuse

figure 4



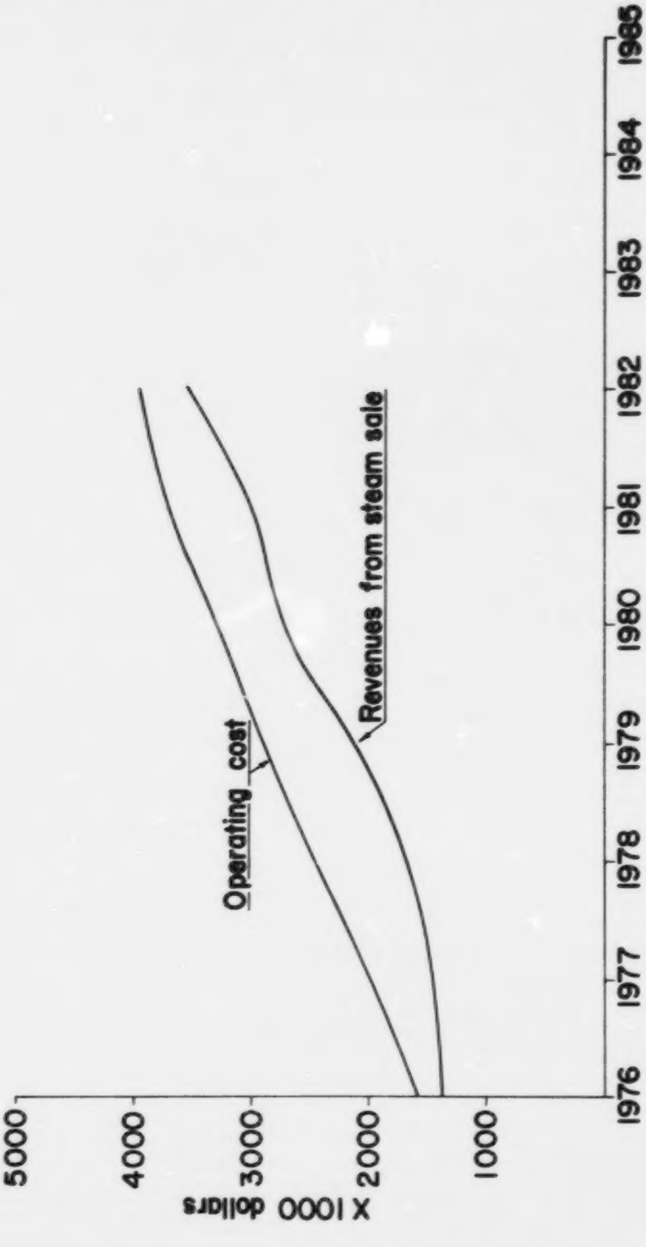
Inside cut-away view of the modified furnace

figure 5



Operating cost and revenues from steam sale

figure 6



District Heating Project Implementation "A Developer's View"

by:
Thomas R. Casten
President
Cogeneration Development Corp.
350 Fifth Avenue, Suite 1134, New York, NY 10118
(212) 239-7233

Introduction

Implementing a district heating project is a long and complex process in which every step is interrelated to several other decisions. The process can be likened to solving a Rubik's Cube in which each turn affects three other faces and 12 elements. This presentation will offer some sense of the time involved, of the key steps, and will offer some ways to solve the "district heating" cube more completely – i.e. produce more profitable projects. Apologies to a Canadian audience for the emphasis on a U.S. project, but we believe the experience relevant, with slight changes to reflect unique Canadian law and regulations.

Implementation – A Rubik's Cube

Each district heating project will have six major areas of decision or impact, just as a Rubik's Cube has 6 faces. The areas are:

1 Technology Choice

2 Thermal Loads

3 Economic Feasibility

4 Regulatory Approval

5 Contracts

6 Financing

Over the past 8 years and perhaps 400 cogeneration project possibilities and ten district heating project possibilities I have learned that none of the choices are immediately obvious. Many first, second, and even third approaches are later replaced by more optimal technology, or by change of some other variable that turns a marginal project into an attractive project.

Each time an apparent snag is encountered, there is usually a way to solve it by changing several of the parameters in other areas, just as one changes the top face of a Rubik's Cube only by affecting several other faces. This may seem so obvious as to not bear mentioning, but in fact many would-be projects have been killed because the early feasibility studies were performed with a fixed assumption about the technology choice, or the thermal loads, or the contracts possible.

Trenton District Energy Co. – A Case Study

The Trenton District Energy Company (TDEC) project history will illustrate some of the interrelationships that have been manipulated to produce a financeable, legal, economically attractive project.

Trenton, New Jersey is an historical old industrial city of 92,000 population that is the capital city of New Jersey, and as such is home to the New Jersey Legislature, State office buildings, a major State prison, and all of the supporting private offices. Trenton's once proud industrial base has been reduced by the changing economics of basic industry, but it still enjoys numerous large employers, including Congoleum, DeLaval, U.S. Steel and General Motors.

In 1977, Mayor Arthur Holland and his City Planning staff looked at their City and thought a downtown district heating plant powered by cogeneration might be feasibile and might help revitalize their City. They obtained Department of Energy grant money, put together a team consisting of the local electric utility, Public Service Electric & Gas Co. (PSE&G), an architect, an engineering firm, and a contractor. This team spent a year and $800,000 producing quite an elaborate feasibility study.

The plan that emerged was to join roughly 20 State office buildings together into a *steam* district heating network powered by the cogenerated waste exhaust gas from four 2.5 megawatt combustion turbines which would generate 45 million kWh of electric power for sale to or use by the public utility, Public Service Electric and Gas Co. (PSE&G). The turbines were to supply almost all of the heat and were therefore to track the fluctuating thermal loads. This left the annual electrical load factor at only 51%.

PSE&G concluded that the project was not viable and dropped out of the team. The architect, Carl Stein, was reluctant to give up; he was convinced that a workable plan could be devised. The project in its initial technical conception employed a lot of capital for generating equipment, which did not operate very often because thermal loads were too low.

The "Rubik's Cube" of the first team was not solved. Something else had to be done.

The first "twist of the cube" was to increase the system's thermal loads. The project engineers said steam could be transported economically for 2 miles, and a 350 bed hospital was found at roughly 2 miles from the generating plant. It required an extra million dollars to reach, but this seemed feasibile. The new thermal loads would increase generation to over a 70% load factor, improve economics, and improve expected rate of return. But still the project faltered.

When my organization was asked to take over the development in May of 1980, we found a project that was apparently legal, was marginally economic, and hence was not, in our judgment, financeable. However, there were a number of ways to further "twist the cube".

Technologically, we instantly scrapped steam as a distribution media and went to high temperature hot water, using the pre-insulated piping systems that have been so well developed in Europe. Our system would have 100% return of cooled water, would eliminate all steam traps, would eliminate fear of rotting condensate pipes, and could be installed for only a slight increase in costs over steam. This change to a hot water media for distribution cut projected distribution thermal losses from 18% to 5%, which was useful, but not the critical impact. With returning low temperature hot water, TDEC would no longer be restricted to the use of only high temperature exhaust heat recovery. TDEC was no longer restricted to gas turbine cogeneration.

The project could now use reciprocating engines with their significantly higher electrical output, and recover jacket water heat. Now the project was to have a 12 megawatt electrical generation plant that could run all the time at full electrical load, maximizing cogeneration. The projected load factor rose to 92%. The reciprocating engines have lower gross fuel rates per kWh but lower recoverable heat than combustion turbines. Possible recovery is 3100 BTU/kWh vs. 5800 BTU/kWh for the turbines. This change would allow production of 100 million kWh per year with full heat recovery.

Note: The problem with reciprocating engines is that only 2100 BTU/kWh are recoverable from exhaust at steam send-out temperatures. The remaining 1000 to 2000 BTU's per kWh come from the jacket water at 190°F, the oil cooler at 150°F, and the after-cooler at 105°F. Only a small part of the thermal energy in the latter three sources can be used to pre-heat feedwater in a steam system, whereas all jacket and some lube oil heat can be used on a hot water system.

The following chart compares heat recovery with each technology to illustrate the dilemma.

Gross and Net Heat Recovery for the Turbine and IC Engines – All in BTU/kW

BTU to Prime Mover per kWh Produced	8,700	11,700
Less Exhaust Heat Recovery (125 PSIG steam)	(2,120)	(4,280)
Net Fuel per kWh after Exhaust Heat Recovery	6,580	7,420
Net Fuel per kWh after Credit for 80% Efficient Boiler	6,050	6,350
Other Heat Recovery Possible		
Jacket @ 200°F	927	– 0 –
Lube Oil @ 160°F	458	– 0 –
Charge Air @ 100°F	600	– 0 –
Possible Net Heat Rate	4,595	7,420
Possible Net Heat Rate after credit for 80% efficiency Boiler	3,568	6,350

One more technological innovation was introduced that appeared to cause the "economics" face of the Trenton cube to twist into place, i.e. to become attractive and financeable. This last change of technology was to add supplementary firing to the exhaust heat recovery boilers. The engine exhaust would contain 11 – 12% free oxygen which could support further combustion at incremental fuel efficiencies of 95% (no need to heat ambient air to the boiler exhaust temperature, a normal fuel waster). The earlier plans had used conventional boilers operating at 82 – 85% efficiency for all heat above the engine recovery level. TDEC gained 10% fuel efficiency on 300×10^9 BTU of heat production.

The Contract Face

Developments at this stage moved to the "contracts" aspect of the cube solution, and suddenly TDEC was back to a near marginal project. Neither of the key thermal users, the State of New Jersey or the Mercer Medical Center could justify TDEC's requested starting thermal rates – rates which produced first year, second year, and even third year losses. It was now the "contract" face that had to be "twisted" by lowering the rate structure. Negotiations to sell the electricity were going nowhere, and new federal rules that mandate electrical purchase by local utilities at fair prices were not yet implemented in New Jersey. TDEC was trying to sell electricity to a municipal utility in Vineland, New Jersey, 60 miles away, and local politics were arcane. PSE&G regarded the project at this stage as highly unlikely and did not negotiate seriously.

New thermal loads saved the day and the project. An existing New Jersey State Prison was added as a customer. Although the prison was one mile beyond the far end of TDEC's then planned distribution, it had steady year-around loads. The prison had just committed to install 1500 tons of new high temperature absorption chillers that would use heat all summer. This addition allowed the economics to return to a financeable level, even with a lower thermal rate schedule. The State and Mercer Medical Center both agreed to sign 20 year contracts.

This step started to build political momentum and helped TDEC to reach agreement with Public Service Electric & Gas for a sale of all electrical output under a rate formula which covered capital and Operating & Maintenance, and tied the fuel payments to 7800 BTU's per kWh of TDEC's fuel, at TDEC's cost for fuel. The only tough spot, it seemed then – April of 1981 – was that the contracts were "take as delivered" not "hell and high water". We had to somehow assure performance.

When one talks contracts, it is not just contracts for the sale of electrical and thermal output. To solve the TDEC "cube" ultimately took a series of added contracts including:

1. A stipulated sum turnkey construction contract backed by a 100% performance bond. This was reached with a joint venture that includes Foundation Limited of Canada.
2. A 10 year maintenance contract from Cooper Industries, the engine vendor, which has a fixed ceiling on real maintenance costs and which has fuel conversion guarantees – Cooper must pay for all fuel used by TDEC above a specified level of BTU's per kWh.
3. Business interruption insurance.
4. A New Jersey State obligation to operate the project in the event of a major outage to continue until the issues of bankruptcy were decided by a competent court.

With all these pieces in place on the "contract" face of the TDEC cube, financing could start to be firmed up. The United States Department of Housing and Urban Development (HUD) agreed to make a $4 million grant to Trenton for loan to TDEC at favorable rates. The New Jersey Economic Development Agency authorized the sale of $10 million of tax-exempt Industrial Revenue Bonds. The plan had been to raise another $3 to $5 million in private equity and complete the $17 – $18 million financing.

The "Cube" has Other Faces that Move

Here in the TDEC story comes a clear indication of how the "cube" always seems to interrelate. In twisting the technical and thermal load face of the "cube" to add more users, more pipe and more generation, TDEC had pushed construction costs to $19 million. Debt service reserve, interest during construction, fees, etc. pushed total capital to $25 million. But projects that use tax-exempt revenue bonds cannot exceed $20 million expenditure over the six year period that brackets bond takedown. If TDEC could not issue the $10,000,000 bonds at tax-exempt interest rates, project economics would slide again.

The solution finally adopted was a change in the financing structure to a lease of all generating equipment, essentially selling the tax benefits for equity. Fitting this lease to the by now complex project proved difficult enough, and was rendered much more difficult by narrow Industrial Revenue Bond rules mandating that the lessor must be "in the trade or business of leasing like or similar equipment". Given that some aspects of TDEC are firsts in the USA, lawyers were greatly perplexed as to what lessor would qualify. Without clear qualifications, the leased equipment might be deemed a part of TDEC's capital expenditure and the bonds would become taxable. Many months were lost finding a lessor who would have no doubt about qualifying under IRB rules.

In August 1982, an outside force intervened and gave the financing face new life. A new U.S. Tax Act was signed, and one obscure provision allowed district heating facilities to be exempt from the small issue test – allowed for unlimited use of the tax exempt Revenue Bonds to finance thermal distribution systems and user substations of district heating projects. Suddenly, the problem we had fought for months, spent hundreds of thousands of dollars solving, and had solved, became a non-problem. The best analogy here is my son's Rubik's Cube solution – namely the taking apart of the cube. Unfortunately, the new law only put in place one face. We believe, incidentally, that this access to tax-exempt financing is essential and will be needed in Canadian projects as well.

The Regulatory Face

In parallel, the regulatory "face" had to be solved. Problems here are unique to the United Staes, but there are many parallels, I'm told, in Canadian regulation. One particularly troublesome part of the regulatory "face", the Fuel Use Act (FUA), was found to be in place because of legislative oversight. The Fuel Use Act requires all large new installations to burn coal unless they are granted an exemption on economic or environmental grounds.

TDEC had absolutely no economic way to burn coal. New Jersey law requires 0.5% sulfur coal in Trenton which explains the complete absence of coal boilers in Trenton. The project, to be economic, had to use oil and/or gas, and seemed to be theoretically able to pass the economic exemption test of the FUA, but time was a killer. TDEC was told by the Energy Regulatory Agency that the FUA exemption process would take at least nine months.

Unknown to TDEC when the switch from turbines to reciprocating engines was made, the project became exempt from FUA, as the FUA does not have jurisdiction over reciprocating engines. Once in a while, one gets lucky!

The state environmental permit required expensive dispersion modeling and 5 months to obtain – it was relatively easy. The Federal PSD permit was another story, taking a year which was characterized by the excessively slow administration of rules that were never designed for cogeneration. Just to name a few of the problems:

1. No pollution credit was to be given for any of the boilers that would go out of service unless TDEC brought in certificates of destruction – 1½ years before TDEC could offer service.
2. All calculations had to be done with oil instead of gas because TDEC's gas supply is interruptible. This in spite of a history of 8-10 hours annual interruption on the gas service contract in question.
3. When all the dispersion modeling said that at the very worst case, filled with arbitrary negative assumptions, TDEC would meet standards with a 30 meter stack, the EPA ordered a 50 meter stack.
4. When TDEC contemplated "twisting the cube" for different engines, we were told that any change in technology re-starts the whole process.

Final Dressing of the TDEC "Cube"

Add a few random elements such as a rating from Standard & Poors (BBB+), a baker's dozen of minor permits such as historical preservation, canal commission, building permits, planning board permits and the regulatory face seemed complete. Then it was discovered that because TDEC sells heat using "facilities granted by the State or a subdivision thereof", TDEC was subject to regulation by the New Jersey Board of Public Utilities. Actually this had been known, the Board had been approached and in one of their many efforts to help TDEC, the Board declined to exercise their power to regulate. But an obscure part of the New Jersey Public Service rules said that no utility bonds of over 12 months life could be sold without approval by the New Jersey Board of Public Utilites. TDEC had to be approved. A friendly Board acted in three weeks, solving what was perhaps the last major regulatory hurdle.

There followed eight months needed to secure commitments on all financing. The process was slowed greatly by the new tax law as it opened up many opportunites for interpretation. By Christmas 1981, over five years since Mayor Arthur Holland had first begun his drive for district heating, it was finally clear that there could be a project – but only if the developer could obtain a private letter ruling on tax treatment of the leased property. Was TDEC a utility, or a non-utility? Would the fact that 100% of the present thermal contracts were with tax exempt institutions cause the Federal Internal Revenue Service to deem TDEC a lease to the State of New Jersey?

The law firms representing lenders admitted that the issues they raised had little likelihood of unfavorable ruling, but doubt existed. Lenders abhor doubt! With no comparable project started in the past 40 years, much of the relevant tax law had never been interpreted in tax court or by letter ruling. A crash effort was made and public figures' help was sought to obtain an expedited tax ruling. New Jersey Senator Bill Bradley intervened, New York Congressman Ottinger wrote to the Treasury, Federal Housing and Urban Development and Department of Energy officials entered a plea, the United States and New Jersey Council of Mayors and the International District Heating Association added their weight.

Now in November 1982, TDEC is in the closing process, fixing the last of its interlocking contracts to the satisfaction of all lenders and nearing the point of financial closing, nearing the point of construction start. Two more years until full operation.

Lessons and Observations

Before anyone concludes the TDEC experience is a normal time-frame for future projects, it must be pointed out that this has been from birth a cutting edge project, preceding many laws and their regulations that now ease the way. TDEC will not take five years to repeat, but it won't be repeated in five months either. Furthermore, the marriage of district heating with cogeneration raises some tax questions that would not arise for a straight cogeneration project.

There are several observations which can be offered to others developing district heating that are consistent with the TDEC experience, as well as our other cogeneration project experience.

Lessons Offered

1. Technical solutions improve with work. Don't stop with the first approach. Especially don't stop with an approach your engineer has experienced.
2. Adding thermal load can be most valuable and crucial. Think about joining two or more heat users wherever possible.
3. Try very hard to have the user(s) guarantee financing. Attempting pure project financing without such guarantees will easily add a year to the time. If you are one of the users, consider guaranteeing debt service.
4. Avoid adding time if possible. Law changes, even when they are beneficial in the long term, introduce "pendancy" and can stop a good project in its tracks.
5. Forget an electrical sale based on the utilities' costs unless you plan to guarantee the loans. Without user debt guarantees, your project will need electrical sale contracts that relate to future project costs, ditto thermal contracts.
6. Count on and cultivate political help. Cogeneration, especially with district heating is quite attractive to most politicians.
7. Decide early what you are able to do with in-house staff and what help you need. The most expensive course is to learn each lesson yourself.
8. Beware of all who claim experience, especially bankers, engineers, lawyers, equipment vendors, contractors and consultants. Most have a desire for experience and some related experience which is less relevant than either you or they suspect. Insist that your team has earlier hands-on experience.

There are many reasons to develop district heating and the rationale will grow stronger. Economics, energy conservation, lessened pollution and a vital electric utility system are all served by well conceived district heating projects. The road will get easier – has gotten easier – as more players enter the field. The economics are so profound that they ultimately place the city without district heating at a competitive disadvantage. But, like everything else worthwhile, district heating takes a great deal of effort to develop.

They say there are some kids who can now solve the Rubik's Cube in less than a minute. The district heating "cube" will take longer, but we think the reward can be well worth the effort.

Private Sector Involvement in EFW Projects

by:
D. Volter
Canadian General Electric

Abstract

It was with much pleasure that I accepted this invitation to present some thoughts on private sector involvement in what I believe to be an exciting opportunity for the future, Energy Recovery from Waste (EFW). During this presentation we will look at the various components of an EFW Plant, including two of the processes; they are Mass and Starved-Air, often called Modular. The reason for selecting these is simple; they happen to be the processes that we are working with and promoting. Plus the fact that these two are the only ones that I feel comfortable talking about. We will look at three Major Factors: 1. Why 2. Where and, 3. When, in the decision-making process should an EFW plant be considered and then how it should be done.

First of all, we will take "Why"

"Why" should an EFW facility be considered. I believe the first answer is that Refuse is an alternate fuel having an average 4500 BTU's per lb. or, put another way, 1 Ton refuse is equal to 1.25 barrels of oil. Th second answer is that with reductions of 80% to 95% of the volume to be disposed of, it is a cleaner method of disposal than current landfill.

"Where" should an EFW plant be built.

The first choice should be as close to an Energy customer as possible, e.g. a proponent that has a use for process steam. The second choice could be for process steam heating and air conditioning of an Industrial Complex.

"When" should an EFW plant be built:

There is no specific answer to this other than a real desire to utilize refuse as fuel, e.g. to replace fossil fuels for generating steam, when an alternative is required to replace landfill for environmental reasons, and last but not least, is when the economics of an EFW plant over landfill can be seen to be a viable alternative.

Now, let us look at Who the proponents should be in recovering energy from waste. Who has the greatest need, and who will benefit the most.

The first case to be considered is the Municipality or Region that has or could have a landfill problem. That is, the present landfill is near capacity and there appears to be no immediate site that could be used for future development in the same geographic location. What is the solution to this situation? Well, one answer is to haul the refuse greater distances with the possible building of a transfer station and the cooperation of some other Region or Municipality. This is easier said than done, as apart from objections by public sector not wanting to take someone else's refuse, there is the cost of transportation which could be as high as 9-10 dollars per ton. This, at a time when we are being asked to conserve fuel. There are, of course, other factors. Predominantly, the environmental impact of landfill. While this method appears to be still the cheapest way of disposal, the question should be asked: Who wants one in their backyard, and how long can we squander the land we have, and what protection do we offer future generations? By this I mean, contamination and pollution of streams and rivers.

I said that this appears to be the cheapest but is it really the fact when we consider that the site to be used should be reasonably good land which lends itself to control of leachate and reasonably accessible; this means close to development areas where land is not the cheapest. Furthermore, there is the cost of lining with impermeable layers of clay or plastic sheeting, and daily cover to satisfy environmental controls. So, who benefits the most in the first place from an EFW plant? Well! I suggest the public sector. Of course, I can see the reactions now! Surely, there are other beneficiaries. There certainly are, and foremost is the recipient of the energy generated from such a facility. Second, is the proponent that builds such a facility. These plants do not come cheaply which is why it is taking such a long time to get one of these projects off the ground. The third recipient is the local community where one of these plants would be built and this is in the form of local jobs; both in the construction period and the operations thereafter. And the fourth, of course, is Canadian manufactured goods, and the supply of consumables after the plant is operational.

The main reason for my invitation was to present Private Sector participation in Energy from Waste Projects, in particular: "Ownership," "Financing," and "Operations." Let's discuss "Ownership" and what Private Sector would require to make it attractive.

1 A return on investment of about 20-25% over the life of the project is the base requirement for any new venture.

2 Guarantees from public sector that all combustible quantities would be delivered to the site. This would have to include agreements on the price per ton for refuse and a safeguard that if the refuse is not available then the owner would be assured of revenues by the public sector.

3 Guarantees from the energy user for a period of time equal to the debt repayment that would enable the owner to project cash flow.

4 Last, but not least, full support from Government financial or legislative.

What are the ownership options? These could be:

a Private Sector only as a single proponent.

b Joint Venture with the energy user.

c Joint Venture with Public Sector.

d Public Sector only.

If we look at the four base options and examine each, we can, through elimination, select one or two options that are the most tenable.

First, Private Sector: This option can fall down for any number of reasons; the most dangerous of which is the guarantee of waste. The second is the cost of money for such a project, and third, the viability of the energy user, although this could apply to option (c) or (d).

Joint Venture with the energy user offers some degree of protection on energy sales but is still exposed to delivery of waste and cost. There is one more factor and that is "why should the energy customer become involved with the capital cost of an EFW plant other than as an investment, when at the present time he can have gas piped or oil delivered for a fraction of the cost for the service." I am not referring to the fuel cost here.

Joint Venture with Public Sector would appear to alleviate some of the previous concerns but still has a cost impact, ie. Public Sector money versus Private.

Public Sector ownership would appear to be the most positive and protective scenario of all the options – in that it already controls the refuse. It is the sector that could have the future landfill problem, and has the responsibility for controlling public expenditures, eg. tipping fees, and does not necessarily have to make the same return on investment as Private Sector.

What is required to make it more attractive to Private Sector?

In the United States there are in place some very attractive programs which if duplicated here could be extremely interesting to Private Sector ownership. Under private financing most of the money will come from bond issuance with the initiator and operator of the scheme normally investing approximately 20% of the capital requirements.

In order to interest prospective buyers of the bonds, a minimal four conditions must be met:

1 The proposed process must be based on proven technology, and be able to handle and dispose of the refuse for the 20 year repayment period.

2 The operating company must be of substance and inspire confidence in the bond buyers that it will be able to operate the plant for 20 years.

3 The necessary inflow of waste must be guaranteed for the same period. This condition often requires a special approach as some municipalities are able only to enter into agreements of one year duration. Furthermore, the extent to which local authorities can control the waste collected by private haulers is still being disputed in many places.

4 Energy customers must be available which can and will guarantee to take the energy at an agreed price formula for the full 20 year period.

Bond interest levels presently are about 7-11%. Because refuse resource recovery is a public service and conserves energy, the bonds are tax exempt. The owner companies investing the 20% basic capital in the project are able to achieve substantial tax rebates because of its energy conserving nature. These rebates are based on a percentage of the total plant cost and this helps to make this investment attractive.

The price for the energy is guided by the normal price level for energy in the region in question. It will normally have to be about 5-10% under the cost of conventional energy in order to interest energy customers.

Operating costs plus capital repayments less income for energy sales invariably result in a deficit. This deficit divided over the annual tonnage represents the net disposal cost – the "tipping fee" – to be paid by the hauler delivering refuse to the plant. The tipping fee per ton must be competitive with other alternatives in the area to justify the municipality's long time guarantee of supplying refuse as well as attracting the privately collected commercial and industrial refuse.

The following budget is based upon the U.S. price level in Spring 1982 and shows the cost of a privately constructed and operated modern refuse fired steam generating plant with a design capacity of 1000 tons of refuse per day. Land costs are included and the plant is constructed with pollution control equipment to meet general standards.

Waste-to-Energy Plant Cost

Capital Costs	
1000tpd plant	$60 Million
Bond Reserve and other financing costs	$30 Million
Total	$90 Million
Costs per Ton (300,000 tpy)	
Debt Service @ 11% (tax exempt)	$31.00
Operation & maintenance	$15.00
Total cost per ton	$46.00

Impact of Inflation on Cost of Resource Recovery

	Costs per Ton	
	1982	1987
Debt Service	$31.00	$31.00
Operation & Maintenance	15.00	30.00
Gross Cost	$46.00	$61.00
Energy Credits	28.00	56.00
Net disposal costs	$18.50	$ 5.00

Assumptions

1 Continued cost escalation of 10% per year (costs double in 7 years).

2 O & M and energy credits escalate at general inflation rate.

The net disposal costs – tipping fee – must be competitive with alternative disposal costs.

However, the most competitive alternative is normally the "sanitary landfill" the cost of which varies from one part of the country to another influenced by the following factors.

Factors Affecting Land Disposal Costs

Land – Cost
– Availability
– Distance from Source
Regulation (RCRA) – Permitting
-- Public Acceptance
– Geology
– Engineering
Operations – Labour
– Fuel
– Environmental Control
Post Operations – Equipment
– End Use
– Perpetual Care
– Liability

The diagram on this slide indicates the present national range of landfill disposal costs and – for the plant type and size mentioned above – the influence of energy costs on the viability of a refuse fired steam recovery system.

I believe that advanced refuse burning facilities with energy recovery have a great future in North America with the present development in landfill costs and energy prices.

The remaining 80% will normally be met by issuing industrial development bonds. These are tax exempt and repayment of the bonds is derived from the revenues of the project. In exceptional cases, the community being served by the resource recovery facility may issue general obligation bonds, which entails that the repayment is guaranteed by the taxpayers of that community.

Financing

It is no secret that Public Sector can raise money a lot less expensively than Private Sector. And when you consider that a couple of percentage points on a multi-million dollar project can either make or break that project, then Public Sector should never be considered as anything other than first choice. Having said this, though, we should remember that as and when landfill or land costs and transportation reach the levels that are being projected, there will be a real opportunity for Private Sector to participate in sole ownership. I have drawn these two examples of the differences in Public versus Private to show what I mean in today's dollars.

Operating an Energy from Waste Plant

We have been talking about ownership and financing and the impact on an EFW Plant. But one thing is certain and that is, when we talk about operations there is only one practical way to go and that is an operational contract with a waste management company. "Why?" The answer lies in the conditions that can be applied to an operating contract.

1. A firm price can be obtained that can be applied to an operating contract.
2. The incentive for the operating company to perform at maximum efficiency.
3. Because there are so few plants of this nature in existence in North America, the experience of these professionals can be utilized to the full.
4. This is really an extension of the last condition and that is design. Whoever the owner is, if it is intended that an operational contract will be sublet then the operator should be identified in the conceptual stage of an EFW Plant. Why do I make this statement? Well, imagine if you will, the problems that the handicapped have had until very recently trying to operate in a world that did not address their needs, for example, no elevators, only stairs or escalators. Revolving doors, no ramps to get on and off a sidewalk. Public Transport vehicles. The list is endless and if we think about it, I am not just talking about independence, I am addressing efficiency.

   If the design of a new building or transportation system or whatever, incorporated the needs of the users, then we would have a practical and efficient product. The design of an EFW Plant is no exception. I believe that history has already shown us that there are some awfully big white elephants in the world because there was not enough thought or cooperation applied. I am always reminded of the fellow who built a boat in his backyard then had to knock part of his house down to get it out and then prayed for a flood so that he could get to the sea. There are so many aspects of the operations that should be a part of the design of an EFW Plant.

For a new owner who has absolutely no track record in operations, it would be similar to inventing the wheel when the buggy has already been invented.

I said earlier that I would touch on the two methods of incineration and energy recovery that my company is involved in and they are Modular and Mass. I will try not to bore those of you who know the difference but primarily we work with Volund (Mass) and Consumat (Modular).

Volund (Mass)

This is the front runner in today's technology, with over 350-400 full-scale plants in operation around the world, some with up to 40 years of continuous operation.

These plants are best utilized at 100-200 tons per day and upwards.

The characteristics are:

The waste is fired as loaded into the furnace from the feed hopper.

Temperatures in the furnace are set to reduce ash deposits in the furnace and boiler and to avoid nitrogen oxygen formation. About 100% excess air is used for corrosion control.

Low gas speeds in boilers to control erosion and pollution.

The design of the grates and boilers is specifically for solid waste handling.

"Starved Air" or Modular

Modular has a place in the 150 TON PER DAY and smaller and again, is a front runner in solid waste technology. There are, I believe, approximately 100 plants in operation; mostly in the United States – and have been in existence for the last 10 years.

Characteristics

Again, the solid waste is fired as it enters the lower chamber at relatively low temperatures.

Excess air is used in the secondary or upper chamber and in the case of Consumat, an auxiliary fuel is required, approximately 250,000 BTU's per ton for complete burn and control of pollution.

Modular has a relatively low net energy recovery but should not be compared to mass on evaluation as it has a relatively low cost to build one of these plants compared to a Mass plant.

If we look at these two elevations, you will see that there is a considerable difference in the Civil and Structural design.

Operationally, the Mass system can be operated with a smaller staff than Modular as the feeding of the Hoppers and the Plant Control can be carried out from a central control room by one man as can be seen in this view of the AARLBORG PLANT.

As I said earlier, both have their own respective applications and place. Indeed, when I stated earlier in this presentation that there is a "WHY," "WHERE," AND "WHEN" with regards to the decision on whether an EFW plant should be considered. I should have also added "WHAT" size should it be? The answer to this question is very simple and reminds me of my wife who always answers my question with a question and that is: how much refuse is available for processing and if we wish to compound the question, how much steam or energy is required.

If oil prices had continued to spiral the way they did in the early '70s, I believe that we would have seen a faster development of alternate energy sources which would, of course, have included EFW plants and I believe a more intense involvement by Private Sector.

The Financing and Risk Sharing of Energy from Waste Facilities in Ontario

by:
D. R. Craw
President
Leaseguard Financial Services Co.
P.O. Box 129, Suite 1500, Toronto, Ontario, M5L 1K5

Introduction

The analysis and selection of a vehicle for financing an Energy From Waste ("EFW") facility is often left until the technical, economic feasibility and environmental assessments have been completed. While initially this would appear to be a logical sequence of events, this approach can limit the time available to evaluate the project's financial parameters. The net result is that some of the benefits can be overlooked. My purpose in today's discussion will be to demonstrate the importance of structuring a transaction in co-ordination with the technical and economic analysis if the financing is to create significant savings over the life of a project.

As a basis for our discussion, I have made the following three assumptions:

1. EFW facilities in terms of the dollars invested and technology employed can cover a broad spectrum of projects. Given the topic of this session, my comments will be directed to the financing and risk sharing requirements of municipal solid waste ("MSW") facilities. However, it should be noted that the analysis described should be considered within the financing of all types of EFW transactions.
2. While some MSW projects producing a single product can be built for $5.0 to $10.0 million, the MSW facility within our discussion will produce steam, electricity and hot water and will require a $30.0 million investment. This is significant in that the investment is large by comparison to the Municipality's or End-User's alternative capital projects completed on an annual basis. If the Municipality or End-User is required to account for the full cost of the project, the impact would be a distortion of the borrower's balance sheet.
3. It is assumed that the Municipality and the End-User are non tax paying corporations.

Within the process of analyzing the method of financing a MSW project, there is a tendency for the borrower to utilize a debt instrument such as bonds, debentures, commercial mortgages or term financing. Each of these vehicles are familiar and provide a degree of liquidity. However, they ignore one very important element of a MSW project, namely the capital cost allowance ("CCA"). MSW equipment falls into Class 34 providing a Canadian tax payer with a 25%, 50% and 25% write-off in the first three years of the project. Given the municipality or end-user in our discussion does not pay tax, the CCA which can produce substantial savings is lost unless it can be utilized by a tax paying third party. The method of financing a MSW project which can transfer the CCA benefits to a third party and at the same time retain many of the characteristics of a debt instrument is lease financing. Leasing as a method for the financing and risk sharing of your MSW facility is the major instrument which I would like to address today.

While I could describe for you the structure of the Canadian lease market, its history and participants, in order to remain within the structure of this session, I will characterize today's lease market with the following four comments:

1. Leasing is viewed by many people as a market comprised of cars and computers. While these assets are important, other types of equipment being leased today vary from an $8.82 bread tray to mining equipment costing $70.0 million and up.
2. While some leasing companies promote leasing as a cost plus form of financing, Project Leasing, depending on the type of

asset leased, can provide long-term financing at a fixed interest rate below your alternative debt cost.

3 While leasing is a relatively new concept when compared to bonds, debentures and commercial mortgages, many financial institutions and private placement sources of funds are beginning to recognize that leasing is an attractive form of investment.

4 Leasing, in its simplest form, should be viewed as tax trading (selling) the Capital Cost Allowance to a Lessor, in exchange for receiving a lease rate which is below the alternative debt cost of purchasing the asset. This is particularly relevant for non-taxable corporations who can benefit from the savings generated by trading the Capital Cost Allowance to a third party.

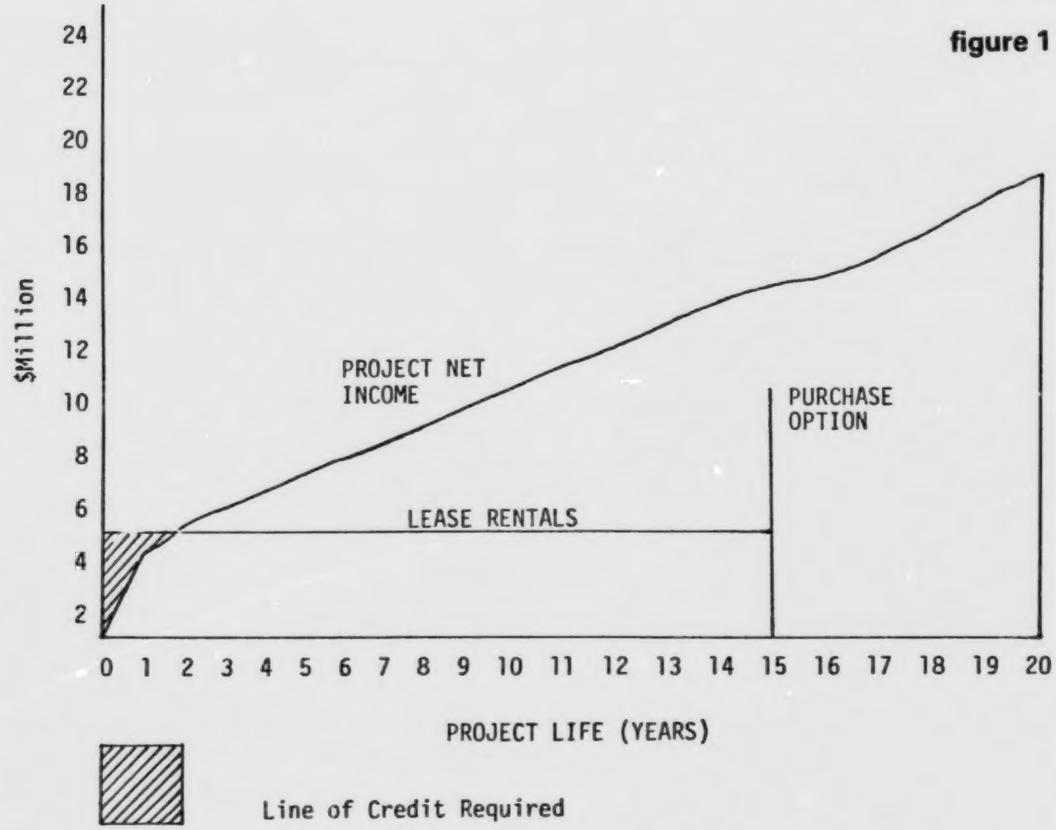
Combining the above characteristics, consider the following example which demonstrates the advantages to be gained by a municipality through leasing:

Lease Analysis Assumptions

Municipality/ End-User 15-Year Debt Rate:	14.0%
Investment:	$30.0 million.
Equipment:	MSW project which, for the purpose of claiming capital cost allowance, falls into Class 34.
Lease Rentals:	15 equal consecutive rentals payable semi-annually in arrears in the amount of $4,276,000.
Purchase Option:	$4,500,000 at the end of the 15th year.

The net effect of the above lease in relationship to the net operating income of a MSW project is illustrated in Figure 1.

figure 1



Lease Investment Analysis ($000's)

P.	Rentals/ Purchase Option	Capital Cost Allowance	Taxable Income	Tax @ 50%	After-Tax Cash Flow
0	0	0	0	0	0
1	4,276	4,276	0	0	4,276
2	4,276	4,276	0	0	4,276
3	4,276	4,276	0	0	4,276
4	4,276	4,276	0	0	4,276
5	4,276	4,276	0	0	4,276
6	4,276	4,276	0	0	4,276
7	4,276	4,276	0	0	4,276
8	4,276	68	4,208	2,104	2,172
9	4,276	/	4,276	2,138	2,138
10	4,276	/	4,276	2,138	2,138
11	4,276	/	4,276	2,138	2,138
12	4,276	/	4,276	2,138	2,138
13	4,276	/	4,276	2,138	2,138
14	4,276	/	4,276	2,138	2,138
15	8,276	/	4,388	4,388	4,388

Lease Investment Summary

Lessor's Yield:	16.2%
Municipality/End-User Debt Rate:	14.0%
Lease Rate:	12.0%

While Figure 1 and analysis illustrate the impact of leasing a MSW project, a factor hidden by the simplicity of the diagram is the number of groups brought together in a project lease financing. Invariably, each party enters the negotiating arena with different priorities, time constraints, and levels of understanding. To put this into perspective, consider the following parties involved in a MSW project:

1 Federal Government – FIRE Program

2 Ontario, Ministry of Energy

3 Municipality

4 Project Proponent

5 End-User/Consumer

6 Financier/Lessor

Given the above list, one can anticipate the divergent needs of each group and the difficulty for the parties to decide who will accept responsibility for the completion and operation of the project.

The "Catch 22" is that while the municipality views a consumer as the one who receives most of the benefits and, therefore, should bear most of the cost, the consumer acknowledges the energy savings to be realized but given the current and future anticipated economic conditions would prefer to:

1 Wait until the economic climate changes.

2 Maintain rather than utilize his existing credit lines.

3 Search for someone else to shoulder the responsibility for financing the project.

Within these activities, each party to the transaction tends to miss the point that, ***if a project is viable, it should be able to meet the Municipality's and the End-User's needs and at the same time be self-financing.*** The ability of a project to stand alone is directly related to the risk components within a financing. "Risk Components" is a very vague term which has as many definitions as there are people willing to participate in a transaction. However, let me demonstrate some of the risks that a Lessor will perceive in financing a MSW facility:

1 Within the construction period, the Lessor, whether he is providing interim financing or not, will want to evaluate the contractor's ability to deliver the project on time and within the project's budget.

2 To evaluate the technological risks, the equipment components must be judged in terms of their degree of specialization and the availability of replacement parts. The ratio of equipment content to building structures in the project combined with an assessment of the obsolescence factors is required in order to evaluate the equipment's marketability. The Lessor, like most organizations, has an aver-

sion to being the first investor in a project. To overcome this hurdle, the Lessor will want to inspect similar projects which are currently operational. Within the assessment of the technology, a Lessor will want to define the characteristics of a mature project and to analyze the factors which could delay the time required for the project to reach maturity.

3 The ability of the Municipality to deliver the waste will be considered as well as the composition/BTU content of the waste, the Municipality's collection process, landfill accessibility and projected growth in relation to the project's capacities.

4 An evaluation of the project's cash flow projection and the assumptions made to create the cash flow is critical to the Lessor's investment decision. While the cash flow will be viewed under different scenarios, the lease will also be structured under different parameters to measure its impact on the project.

5 On both sides of the project the "take or pay" contracts relating to the tipping fees to be paid or the pricing of the energy products must be structured to satisfy both the Municipality's and the End-User's requirements. Penalties for non-performance would be negotiated.

6 The availability of labour and management and the expertise necessary to run the project are part of the Lessor's risk assessment. The decision to provide management on a contractual basis or to use existing personnel or some combination thereof would be considered.

7 Having assessed the project, the Lessor will now turn his attention to a credit analysis of the Municipality and the End-User. While the organization's history and performance are important, the Lessor's greatest need is to satisfy himself that the participants can stand behind their warranties and demonstrate their ability to survive in good and bad economic conditions.

Having completed the risk assessment, and recognizing that the return required by the Lessor and as such the lease rate is in part influenced by the amount of risk which the Lessor perceives, the next step is to quantify the risk elements. Having quantified each element, a structure can be built to control the risk.

At the end of this process, all of the parties to the project are in a position to decide who will accept the responsibility for each risk element. For example, the resource risk analysis, the Municipality may decide to accept the responsibility for ensuring that the BTU content of the waste will not fall below a negotiated level.

As each risk is understood and assumed by one of the parties to the transaction, the Lessor increases his willingness to view the project as an independent financing and reduces his need to look to the financial statements of the Municipality or End-User.

In summary, let me demonstrate the savings which can be realized through leasing. Given a 14.0% debt cost and a 12.0% lease rate, based on a $30.0 million project financed over 15 years to a 15% purchase option, the 2% cost savings when discounted at 14% to their net present value is equal to $6,140,144. On an annual basis, the 2% differential provides a $495,000 savings. This level of savings underscores the value in committing the resources necessary to complete a lease financing.

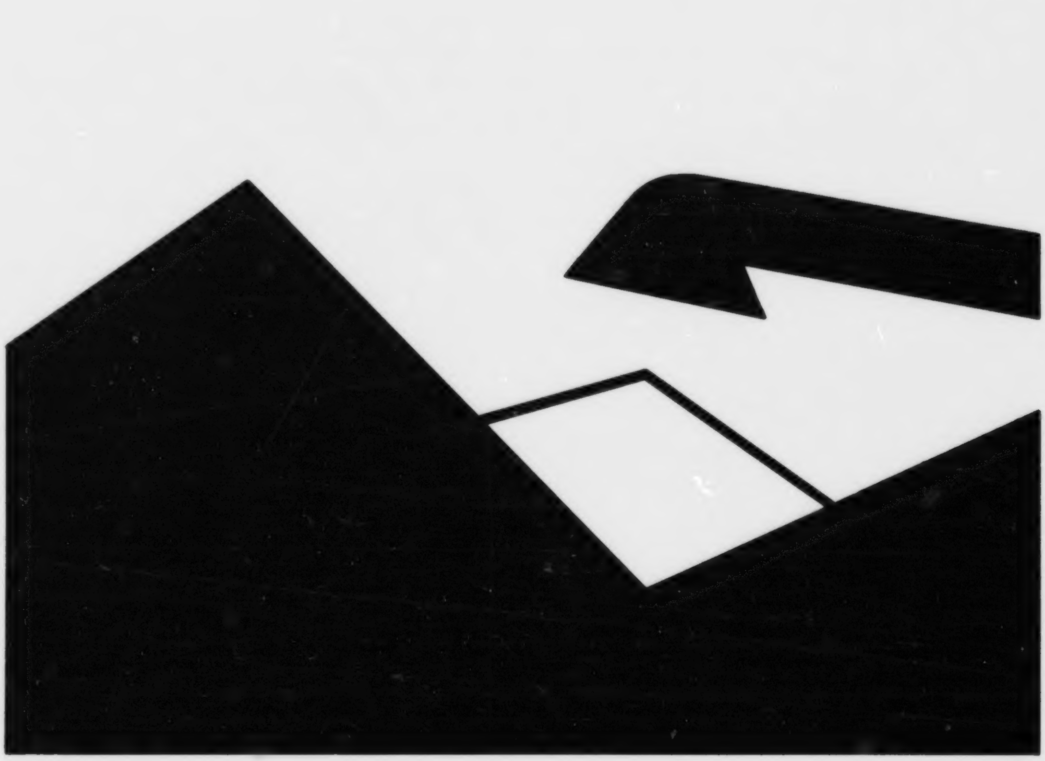
I would like to close by highlighting three points:

1 Leasing is a viable alternative for funding MSW projects on a self-financing basis. Through the Lessor's usage of the available capital cost allowance, leasing can increase the return from a project and at the same time reduce your cost.

2 Within an evaluation of the potential MSW projects represented in this room, there could be found many common elements. However, each project is unique and the risk elements attributable to each system must be evaluated independently and in relationship to the requirements of each party to the transaction.

3 In any project financing, it is important that one group be willing to accept the responsibility for assessing each participant's requirements, for creating the structures necessary to reduce the risk components and for completing the transaction on a self-funding basis to each party's satisfaction. As Project Financing Co-ordinator, Leaseguard fulfills this role in the Financing and Risk Sharing of MSW facilities.

Forest



Use of Wood for Energy in Ontario – Implications to Forest Management.

by:
E. Markus
Director
Timber Sales Branch
Ontario Ministry of Natural Resources

Good afternoon. It is a pleasure to be with people who share an interest in the role of wood as a source of energy.

After a century of decline, wood is making a comeback as a source of energy. Until about 10 years ago, sawmill residues and wood bark were regarded as an abundant nuisance. Now those residues are being burned to provide heat, or steam for electricity – or, increasingly, as a source of fibre for other wood products.

At the same time, there is a growing demand for fuelwood – more than one million cords were burned in Ontario homes and cottages in 1980.

One of our main jobs in forest management is to reconcile the various demands for wood while planning to meet those demands, and recognizing of course that over the long haul, social and economic factors will largely determine priorities in the harvesting of our forests.

To highlight the significance of forestry in Ontario I would point out that the Ontario forest industry accounts for seven per cent of the total value added from the province's manufacturing sector. The industry's shipments had a value of more than seven billion dollars last year representing 22% of Canada's forest products output, of which one-third was exported representing 17% of Canadian forest products exports. The industry provided direct employment for 80,000 people and another 80,000 jobs indirectly. It is the lifeblood of northern Ontario providing 79% of manufacturing employment in the northwest and 34% in the northeast. You can readily see that the health of the existing forest industry is vital to the economy of Ontario.

With respect to forest products, you might picture a triangle whose three sides represent the three main uses of wood – one, fibre-related, producing products such as newsprint; another, solid wood, yielding high value lumber and veneer; and the other representing currently underutilized material going into products like particleboard and fuelwood.

This triumvirate is not static as the marketplace for wood products is dynamic and affected by many factors. The activities in the first two sectors – that is, fibre-related and solid wood – generate potential fuelwood as a by-product. A downturn in lumber markets such as we are now experiencing has a significant effect on by-product supplies as harvesting for conventional products slows dramatically with the resultant decrease in wood residue production.

To illustrate the principle of the supply/demand interaction in real terms, I would point out that our Algonquin region now represents Ontario's major potential supply area for heavy hardwood fuelwood. But the equation could change if for example a major pulpmill capable of utilizing low grade hardwood were to be located there.

As the French expression goes, the more things change the more they remain the same. The concern for fuelwood supplies is not new.

The cry for better forest management was sounded more than a century ago. A letter published in the March 1869, edition of the Ontario Farmer worried about the "savage assault" on the pervading forest. Let me quote from that letter; "The hardest labour a farmer has to do in winter is chopping firewood. Nearly all farmers whose land is wooded carry on an incessant warfare with timber. In fact, so much has been chopped from our forest that wood is becoming scarce and dear. Should there not be some way of remedying this evil? If our woods disappear so rapidly during the next century as they have, what will the coming generations do for fuel?" End of quotation.

The farmer who wrote that letter could foresee what would happen from the evidence around him. Fuelwood production in Ontario peaked in 1881 at 5.4 million cords. By 1910, a large number of farmers in southwestern Ontario were burning coal because they had hacked down their trees to plant other crops.

More than a century after that letter-writer's lament, in the face of shrinking supplies or non-renewable energy forms, his question is again pertinent – what will we do for fuel?

For those of us gathered here today, the question is also, what is the potential for the use of wood for energy in Ontario and what are the implications to our forest resources?

The Ontario government has set a goal of achieving 37.5% of Ontario's primary energy needs by 1995 from indigenous sources – with 3.2 per cent of the total to be supplied by energy from all forms of waste. More than half of the energy-from-waste target – actually 56 per cent – is projected to come from wood in the form of currently underutilized residues and intentionally produced biomass.

This source, it is hoped, would displace the energy equivalent of 15.2 million barrels of oil annually. That's enough to heat more than a half-million homes. It translates into using about four million cords of wood for energy annually.

On the question of the potential for wood energy use, let's first look at the supply side. Wood for energy purposes could be derived from six main sources in Ontario. These are: sawmill residues, logging residues, salvage of dead or dying timber, unmerchantable material from thinnings, low grade material from stand conversion and stand improvement operations, and plantations of species such as hybrid poplar.

Let me elaborate on each source:

1 **Sawmill Residues** include residue in the form of bark, sawdust, shavings, slabs, edgings and chips.

2 **Logging Residues** include slash in the form of tops and unmerchantable stems remaining in the logging area and on landings, and unmerchantable standing timber left as residuals in cutover areas.

3 **Salvaging** dead and dying timber would include harvesting trees racked by insects, disease, flooding and forest fire. Forest fire is the most devastating injurious agent. In 1980 over 3 million tons of timber was charred around Thunder Bay alone.

4 **Thinnings** include unutilized material, both slash and nonmerchantable stemwood, produced primarily from southern Ontario plantation operations.

5 **Material from Stand Improvement** operations primarily includes low grade wood not merchantable for conventional forest products produced from tolerant hardwood stands in notheastern and southern Ontario; and material from ***stand conversions*** occurs across the province with low grade poplar birch being the prevalent species.

6 **Hybrid Poplar** plantations can be established and harvested on a short rotation basis in response to energy market demands.

To complete the picture of the supply scenario we must address the question of Ontario's forest inventory and the existing commitments to established industry. Let me refer to figure 1.

Based on a productive forest area of 79 million acres Ontario's total annual allowable cut is 14.8 million cunits; 13 million for crown land and 1.8 million for private land.

The actual commercial forest harvest in 1980/81 was 7.5 million cunits, of which 6.13 came from crown land and 1.34 from private land. This represents about 47% of the crown land allowable cut and 74% of that from private land.

That leaves 7.3 million cunits of which 5.5 million is committed to existing industry, 1 million is used for personal use and .8 million is surplus. Actual residue yield in 1980 was 13.6 million BDT comprised of 4.6 million BDT of mill residue and about 9 million BDT of bush residue; 83% of the mill residues were utilized thus leaving total unutilized residues in 1980 in the amount of 9.8 million BDT. Potential additional residue yield that is expected to be available is 9.7 million BDT in total from the committed and surplus portions of Ontario's AAC. In total, Ontario's allowable cut has the potential to make available about 19.5 million BDT of mill and bush residues annually.

Bush residues were virtually unutilized in 1980 because of lack of markets. About 88% of Ontario's 1980 timber harvest was in northern Ontario and given the fact of Ontario's southern orientation of population and industry it is readily appreciated that most of the bush residue generated is not economically available. In short, it can't pay its way out of the bush and largely due to the lack of a market stimulus, both harvesting and mill technology are under-developed.

Improved chipping technology probably offers the most promise. Full-tree chipping would take almost 100 per cent of the available wood but the main stumbling block to whole-tree use is the lack of an efficient method of separating the bark and other biomass from the wood chips suitable for use in pulping. Industry research may be close to the answer to this problem. Eventually, it is expected that most bush residues, because of the high fibre content, will be much in demand for fibre-based products.

Although gathering bush residues for energy purposes poses a difficult challenge, sawmill residues are in growng demand because they are concentrated, accessible and therefore available at attractive prices. Many of you perhaps can recall when mill bark was a glut at the mills and sawdust piles an eyesore. Now, however, sawmill wastes are largely under contract: bark is consumed in mill boilers and even the sawdust piles may be spoken for. To be specific, a survey showed that in 1980 some 99 per cent of wood chips were consumed, 88 per cent of planer shavings, 58 per cent of sawdust and 62 per cent of bark. Use of wood residues for energy would seem to have the best economic potential in areas not served by the gas pipeline such as the sparsely-settled areas north of Lake Superior and

Lake Huron.

The information depicted on this figure and the supporting detailed information is available in a report entitled – "Ontario Wood and Bark Residues – 1981" – this report is available to registrants at the Ontario government booth at this conference and I'm sure you'll find it most informative as it presents the information on a regional basis in much greater detail than I have time to present here.

Let us now look at the demand side related to wood being used for energy. On the industrial-commercial front the forest industry is the only significant consumer at this time. In Ontario, the pulp and paper sector is the third-largest energy user among manufacturing industries, after chemicals and steel. From a 1979 study it's estimated that about 17 per cent of the Ontario forest industry's fossil-fuel-related energy requirements are now met by using mill residues including black liquor recovery in Kraft mills; in 1979 this represented abut 2.5 million barrels of oil equivalent (BOE). If all the mill residues currently incinerated or land-filled were used for fuel, this would raise self-sufficiency from 17 to 26 per cent.

Across Canada, pulp and paper companies have already reduced purchased energy use per ton of output by 14% compared to 1972 levels and have adopted a 1984 goal of a 30% reduction from 1972. Also, I am advised that the Pulp and Paper Research Institute of Canada is engaged in developing technology that would allow fossil fuel to be replaced almost entirely by wood waste.

As many of you are aware, a host of forest industry companies are burning wood residues to supply heat for their operations as well as providing steam for co-generating electricity. Let me give you a few examples: Great Lakes Paper in Thunder Bay and American Can in Marathon are co-generating electricty for their own use. Abitibi-Price, as well as co-generating electricity for its own use, also supplies part of the power consumed by the town of Smooth Rock Falls. In Hearst, Bioshell is producing low-moisture fuel pellets from sawmill residues that are consumed by Abitibi-Price at Iroquois Falls.

As well, Spruce Falls Power and Paper Co., at Kapuskasing has been conducting experiments this past year on the economics of wood energy that involves trucking in the whole tree, branches and all, from the bush to the mill.

While such experiments show promise, the reality is that 72% of total 1980 mill and bush residues produced were not utilized. We expect more short-term demand for unutilized mill residues, primarily in the industrial sector, but we don't foresee any substantial immediate increase in the extraction of bush residues, particularly in northern Ontario, until markets develop to support prices that will cover the high harvesting and transportation costs and permit a reasonable profit.

Apart from the supply/demand picture related to Ontario's existing forest estate I should briefly mention our ministry's work with hybrid poplar. Operational trials in our eastern region and research trials at the Ontario Tree Improvement and Forest Biomass Institute (OTIFBI) at Maple show that annual yields from hybrid poplar managed on a mini-rotation basis (2 year cycle) can be attained that substantially exceed the production rate of native tree species. Yields of 5 ODT/AC/YR might be attainable under a mini-rotation system. The technology is now available for the private sector to get more involved in short rotation hybrid poplar plantations and it is hoped that developing energy markets will provide a stimulus for technology transfer in this area.

Under programs being carried out in co-operation with Domtar Limited, there will be 5,000 acres of hybrid poplar plantations intended for pulpwood production established in the Cornwall area by 1985.

Our ministry takes considerable pride in the fact that Ontario is a world leader in this field and we think that the potential for application of this technology is great with over a million acres of idle land in eastern Ontario alone.

Dr. Louis Zsuffa of the OTIFBI is presenting a paper on hybrid poplar production later this afternoon which will bring you up to date on this subject.

I'd now like to comment on the use of wood for energy in the non-industrial sector. Historically, very little information has been available regarding fuelwood consumption in Ontario households due to the fact that private land figures so prominently in the supply scenario.

However, realizing that fuelwood demand was increasing at a rapid rate we decided to engage a consultant to undertake an Ontario Householder survey to determine the level of fuelwood consumption in Ontario and to obtain other relevant information related to the fuelwood marketplace. The survey was undertaken by Inforesults Ltd. and funded by the Ontario Ministry of Energy. The survey report is available to registrants at the Ontario government booth at this conference. I'm sure you'll be very interested in the survey findings as Ontario's fuelwood marketplace has been examined in considerable detail from both the supplier and consumer perspective. Before giving you some highlights of the survey findings I would point out that the survey response rate was quite high at 36% of the mailed questionnaires. This in itself is indicative of the fact that Ontario householders are keen to co-operate in studies relating to wood and energy.

The survey estimated that more than one million full cords of fuelwood were consumed by Ontario residents in 1980 – and that about

800,000 households in Ontario use some wood for residential heating, mostly as supplemental or backup in combination with oil and electricity.

The prevalence of wood burning in residences was found to be 37% for all of Ontario, but only 2.9% of those burning wood use it as a sole source of heat. When you consider that the survey showed that 73% of woodburners have a residential fireplace insert, wood stove or furnace unit it is obvious that the installed capacity to burn wood is many times the current level of consumption. Consumption averaged 3.8 cords per household in 1980 at 5.1 in the north and 3.7 in the south. 46% of those burning wood for heating purposes started using wood between 1978 and 1980.

Firewood for home and cottage use was found to be largely a do-it-yourself operation as 75% of Ontario woodburners cut, split and haul their own wood. The survey showed that the transportation factor is very important as the average distance fuelwood was hauled was only 9.2 miles at an average cord-mile cost of 81 cents. The average cost to cut, split and haul fuelwood in Ontario, including stumpage was found to be $37 per cord for those carrying out the entire operation. As a full cord of well seasoned heavy hardwood has the BTU equivalent of about 150 gallons of fuel oil, at fuel oil prices of $1.37 per gallon it is readily seen that wood obtained at this cost is a very attractive alternative.

Woodburner manufacturers will be pleased to hear that the made-in-Canada label was preferred – supplying 87 per cent of wood stoves, 92 per cent of the fireplace inserts, 94 per cent of the wood furnaces, 90 per cent of the combination wood-and-oil furnaces and 75 per cent of the wood-and-coal furnaces. Installations of wood burning appliances increased dramatically in the late 70's with over 59% of existing wood stoves being installed between 1978-80.

At big city prices, it doesn't pay to substitute wood for oil but it can make sense in rural areas where wood can be obtained at low cost or from a user's own woodlot. The survey showed that 36% of rural woodburners use wood for heating while only 9.4% of urban woodburners do so.

The map (figure 2) shows the estimated quantity of wood burned in 1980 by MNR region. It should come as no surprise that fuelwood usage is greater where it's cheaper. Almost half the survey respondents got their wood from their own land, one-third from private landowners, one-tenth from fuelwood retailers or mills, and only one-sixteenth from land administered by the Ministry of Natural Resources. In the north, however, about one-third of the fuelwood came from crown land. You will note that 16% of fuelwood consumption occurred in MNR's northern regions with the northeastern region being the highest. The northeastern region is the hotspot for MNR fuelwood permits as more than 8,000 of the 25,000 plus permits issued by MNR in 1981 were in the northeastern region and most of these were in proximity to Sudbury and North Bay.

Most of Ontario's fuelwood, about 84% is consumed in MNR's 4 southern regions with the central region representing the largest demand at 35% of the provincial total. This isn't surprising considering the population in this area. Of the total 1980 fuelwood consumption of 1,125,400 cords, 93.6% was used in residences and 6.4% in cottages. As to the source of supply, well over 80% originated from private land with 50% of fuelwood used coming from householders' own woodlots.

Now let me address the question of the implications of fuelwood use to forest management. I've already indicated that attempting to satisfy competing demands for wood is a primary forest management task. Given the current demand and supply situation as outlined I cannot see any significant conflict in Ontario in this regard with respect to fuelwood.

One impact of the increasing demand for fuelwood from MNR-administered lands is that MNR staff are being spread thinner to administer these operations. To cope with this we are endeavouring to increase the role of the private sector in fuelwood production on both MNR-administrated and private lands.

Since the preponderance of fuelwood demand in southern Ontario is associated with tolerant hardwood stands that are also the source of valuable logs for Ontario's hardwood lumber and veneer industry it is obvious that this is the area for potential conflict. I also include here the areas of tolerant hardwood within economic range of the large urban centres in the northeastern region. While the supply of fuelwood grade hardwood is quite adequate the conflict being generated relates to the quality of the woodlots being harvested and the fact that cutting practices can and are in some cases not being conducted with proper consideration to the residual crop of valuable sawlog-grade trees. Not only are residual trees being damaged but in some cases valuable sawlogs are being utilized for fuelwood. I refer here of course to private woodlots.

If managed properly the expanding fuelwood market has the potential to be the catalyst to give forest management in southern Ontario's hardwood woodlots a tremendous boost due to the fact that the vast majority of these woodlots are in need of improvement cuts and fuelwood markets can make this a profitable operation. Stand improvement cutting in carefully marked woodlots should be done so as to minimize damage to the residual stand of high quality stems. Tree marking should be done by a specialist knowledgeable in the area of stand growth dynamics and local markets for sawlogs.

One of the major problems in forest management, historically has been the virtual disappearance of the market for fuelwood from about 1950 which made it difficult for MNR forestry staff to persuade farmers to improve their woodlots until the recent revival of interest in wood-burning. Our efforts have now turned to encouraging woodlot owners to insist on careful cutting practices and we are having some difficulty in coping with the situation in the face of the fuelwood boom. To assist landowners MNR provides a no-charge forestry extension service. However we are finding that under the current economy that very few woodlot owners are availing themselves of our service. We are alarmed that very few woodlot owners involved in fuelwood cutting are having tree marking done by a specialist.

MNR districts are stepping up their efforts to assist woodlot owners. To help ensure that landowners find competent contractors to undertake fuelwood cuttings, districts are maintaining lists of operators that have a proven track record and this information is provided to woodlot owners. Also, when public inquiries for fuelwood are received districts direct these people to private landowners whose woodlots have been properly marked for an improvement cut.

To provide an additional advisory service we have published a publication, funded by the Ministry of Energy entitled "Managing the Woodlot for Profit." I am pleased to announce that this publication is also available at this conference and registrants can obtain a copy at the Ontario government booth. This publication addresses fuelwood cutting specifically and attempts to put woodlot management guidelines into a readily understandable format. We are making this booklet widely available through our districts and expect co-operation from all those involved in woodburner & fuelwood sales in rural areas for support in getting its message across.

We hope that errant fuelwood operators and unsuspecting woodlot owners will learn to more fully appreciate the need for good forest management practices and make more use of the ministry's advisory services. As outlined earlier, there is more than adequate wood available for fuelwood from bush residues alone and therefore if we can collectively get the right message through to woodlot owners, their fuelwood cutting can be a very positive factor in improving the quality of our southern hardwoods.

Most of Ontario's available residue as outlined earlier is located in the boreal forest area, i.e. northern Ontario. With respect to northern Ontario it must be appreciated that bush residues are by and large located in very remote areas quite some distance from potential users. This means that any company interested in harvesting bush residue for energy on a post-logging basis should first undertake a detailed feasibility study. MNR would be most supportive to any such venture and would provide the best information available from our field offices to assist. Not only would we encourage such utilization from an enegy view but we also recognize that there are benefits to silviculture.

So long as the operation does not occur very long after the harvest cut, residue utilization would assist the regeneration process. On the other hand, further study is required to determine the amount of residue that should remain, particularly on very shallow sites, to provide soil nutrients and seed. I can assure you that in our role of resource manager the Ministry of Natural Resources will be continually gearing Ontario's forest management program to fully consider the rising demand for wood as fuel.

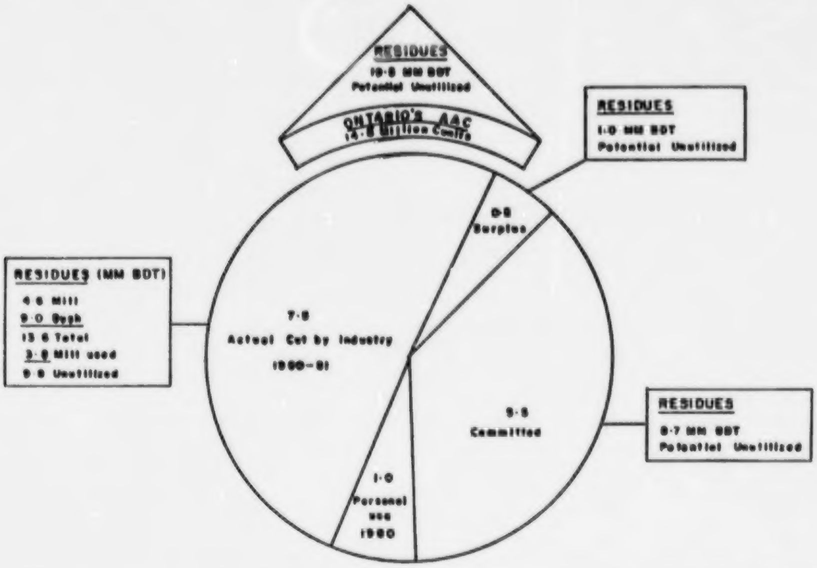
As I mentioned earlier we will intensify our efforts at the local level to ensure that fuelwood cutting in private woodlots is in capable hands while at the same time encouraging more involvement of the private sector in the fuelwood marketplace. In our examination of private land forest policy we will be well aware of the role of private woodlots in Ontario's fuelwood production and the increasing demand for this product.

To assist householders we will continue to make fuelwood available from MNR-administered lands as part-and-parcel of our forest management activities such as site preparation, stand improvement and stand conversion and we will be doing this on an ever increasing scale through contractors interested in developing a fuelwood business as an adjunct to their existing operation.

To stimulate the utilization of residues we will make available as up-to-date inventory information as possible. Furthermore we will continue to work in co-operation with the Ontario Ministry of Energy to undertake special studies in support of residue utilization such as the fuelwood consumption survey outlined earlier and to enhance our efforts in stand improvement operations through special program funds provided through OME, which, incidentally, supported over 4,000 acres of work with fuelwood yield of more than 10,000 cords in 1981/82.

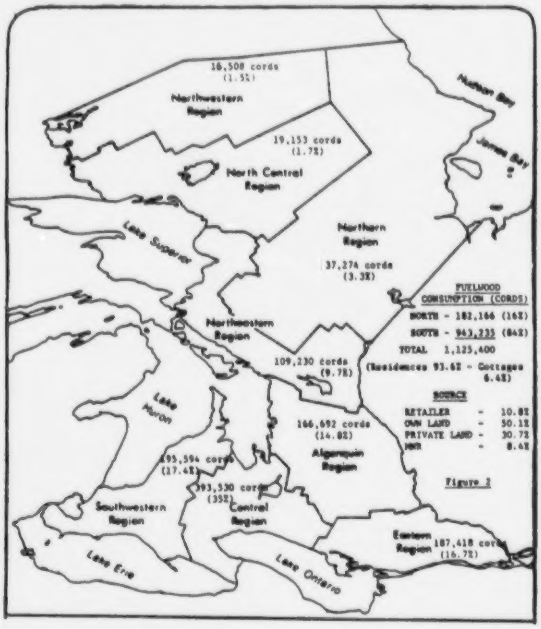
Ideally, the forest products industry should plan to provide fuelwood and other products in one integrated operation thus utilizing as much bush residue as is economically possible with the resultant silvicultural benefit that comes with one-pass logging. Such utilization is of course subject to the dictates of the marketplace and I would hestitate to attempt to predict when energy economics might support such a system on a large scale in Ontario. The potential in Ontario is considerable and with changes in harvesting techniques that will undoubtedly develop with the changing marketplace we can certainly be confident of meeting Ontario's wood-energy targets – and at the same time, hopefully, improving forestry practices.

figure 1



Ontario Ministry of Natural Resources Administrative Regions

figure 2



Energy from Wood in the Pulp and Paper Industry

by:
H. D. Paavila
Canadian Pulp and Paper Association
Montreal, Quebec

Harvesting living trees from the forest, transporting them to the mills and converting them into pulp, paper and paperboard involves a multitude of processes which, in aggregate, consume a lot of energy. The total was equivalent to over 16 million barrels of oil for Ontario in 1981. Most of the energy is utilized at the mill for pulping and paper making. Harvesting and transportation represent less than ten percent of the total. The physical and chemical processes employed at the mill usually take place in the presence of water; in certain processes one hundred times as much water as fibre is being processed. Since many of the processes involve elevated temperatures, it is that requirement to heat the water to carry out the physical and/or chemical reactions and, finally, to evaporate the water to produce a dry product that absorbs much of the total energy input. In actual fact, almost all of the energy input may be accounted for in the increased heat content of the effluent and moist air discharges from a pulp and paper mill. The intrinsic energy content of the finished product is not upgraded by the processes.

Another feature of pulp and paper manufacturing is that a significant, but variable portion of the total living tree winds up as a residual from the various processing steps and must be disposed of in some acceptable way. Over a period of several decades, the pulp and paper industry found ways of reducing the cost of these disposal processes. Indeed, over the past decade as energy has become so much more expensive, this disposal technology has become economically attractive.

Historically, less than one half of the actual tree harvested for pulp and paper manufacture was delivered to the pulp and paper mill. The root structure, limbs and tops were all left behind in the forest. That portion of the tree delivered to the mill must have the bark removed prior to processing it into pulp, paper and paperboard. Since some five million tons of wood containing bark is processed at the mills in Ontario, and since bark accounts for as much as ten percent by weight of the wood, half a million tons a year of bark would accumulate at the mills processing roundwood. Disposal was obviously a problem that had to be solved, and in fact it was solved a number of years ago. Since no other commercial value was found for the bark, the industry was left with two options, landfill or incineration. In the past, much of the bark was removed by a wet process. Thus the fuel value of the wet bark was such that, at best, it was a break-even proposition to burn it when fossil fuel prices were equivalent to 25 cents per million btu's, or less. Nonetheless, since landfill involved expenditures for land, transport and physical handling, bark burning, with its attendant steam generation, was a viable option as much as 50 years ago in, certain instances, in the pulp and paper industry. As technology advanced, which included improved methods of dewatering the wet bark, and development of dry debarking processes, the fuel value of the bark increased. Bark and other solid wood residues available from other forest product industries (lumber, plywood, etc.) were also gradually utilized as fuel by the pulp and paper industry.

There are, unfortunately, no statistics to cover the period prior to 1972 to track this gradual increased rate of solid wood residue burning.

When the OPEC crisis of 1973 triggered a decade of dramatic price increases in fossil fuels, the pulp and paper industry was able to capitalize on the technology it had developed to solve a waste disposal problem. Statistics collected by the Canadian Pulp and Paper Association since 1972 show that pulp and paper mills in Ontario increased their use of solid wood residues from some three hundred thousand tons in 1972 to just under eight hundred fifty thousand tons as of 1981. The increase is due not only to higher product output, but also to a higher utilization rate per unit of output.

Table I gives details. Not all of this wood residue resulted from the on-site mill activities; a portion of it came from nearby sawmill and plywood operations. In fact, higher fuel value justified transport over longer distances. Furthermore, wood product plants have a lower demand for process steam and therefore are not usually in a position to benefit from the installation of a wood refuse fired boiler.

Before wood can be made into paper or paper-

Biomass for Energy

Table I

Solid Wood Residues Used in Ontario Pulp and Paper Mills

Year	Total Production (10^6 tons)	Sol. Wood Res. Use (10^3 tons)	Ratio Residue/Production (lbs/ton)
1972	4.345	306	141
1981	5.227	841	322

board, it must be "broken" down to its individual fibrous components. This process, known as pulping, may be carried out in one of three generic ways. The first, mechanical pulping, involves physical disintegration of the wood into fibre. The other two are chemical processes whereby either an alkaline or an acidic medium is used to dissolve the non-cellulosic binding material in the wood to release the individual fibres. In either of the two chemical processes, a considerable portion of the total weight of the wood is solubilized. The dissolved material consists mainly of lignin, which may be as much as 40 percent of the weight of the dry wood material.

In the "kraft" variation of alkaline chemical pulping, the active chemical ingredients in the pulping liquor are sodium hydroxide and sodium sulphide. Since both are relatively expensive, the early developers of the alkaline process recognized that some form of chemical recovery was necessary to make the process viable. Without describing in detail the long and complex evolution of the system, suffice it to say that this chemical recovery involves separation of the spent pulping liquor from the fibre, incineration in a furnace, and regeneration of the molten chemicals discharged from the hearth or bed of that furnace. This achieves two objectives, to recover and regenerate the inorganic chemicals for subsequent pulping, and to recover the heat released by the combustion of the organic portion of the tree dissolved during the pulping process. The so-called recovery furnace is the heart of this chemical recovery process. I might add that the recovery furnace was a Canadian development.

A parallel development occurred in acid chemical pulping. However, the economics of the recovery process in the acid chemical pulping sector have been much less attractive than in the alkaline.

The chemical recovery process as we know it today was originally developed in the late 30's and is now a standard feature of the kraft industry worldwide. The rapid escalation of energy prices have had less effect on further development of chemical recovery technology since it had already been quite well developed due to other economic considerations. However, optimization of the process has been spurred by the increasing value of credits that may be assigned to fossil fuel replacement that may be achieved through improved efficiency of recovery and use of all of the spent pulping liquor.

In the 10 year period 1972 through 1981, spent pulping liquor use in Ontario has increased from just under 2.5 million tons per year to 2.8 million tons. This is accounted for by both an increase in the amount of chemical pulp produced and by modest improvements in the efficiency of recovery of the spent pulping liquors for incineration, but offset by a slight drop in the ratio of kraft pulp production in the total product mix. See Table 2.

As I have indicated, not all paper and paperboard is made by a single process. The energy intensity of the various processes varies over a fairly wide range of values. However, the aggregate energy requirement of the product mix of the Ontario pulp and paper industry was about 16.6 million barrels of oil equivalent in 1981. Of this, 35 percent came from renewables in the form of solid wood residues, spent pulping liquor and a small amount of captive hydraulic power. In 1972, the figure was 14.9 million barrels oil equivalent, of which 28 percent came from renewables. In absolute values the renewables increased from 4.1 million barrels of oil equivalent in 1972 to 5.8 million barrels of oil equivalent in 1981. See Table 3.

Seven mills have current plans to increase their use of wood biomass for energy. These involve more liquor incineration, and increased combustion of solid wood refuse, either from on-site material or that derived off-site from sawmills and plywood mills. If all of the present plans come

Biomass for Energy

Table 2

Spent Pulping Liquor Use in Ontario Pulp and Paper Mills

Year	Total Production (10^6 tons)	Spent Pulping Liquor Use (10^3 tons)	Ratio Liquor/Production (lbs/ton)
1972	4.345	2462	1133
1981	5.227	2838	1086

Energy Use in Ontario Pulp and Paper Mills

Table 3

(10^6 barrel(s) oil equivalent (b.o.e.) basis*)

	1972	1981
Purchased		
Electricity	1.93	2.47
Primary Fossil Fuels	8.52	7.86
Secondary Fossil Fuels (Distillates)	0.30	0.41
Other	0.02	0.01
Sub	10.77	10.75
Renewables		
Solid Biomass	0.56	1.61
Liquid Biomass	2.76	3.50
Hydraulic Energy (Captive)	0.77	0.73
Sub	4.09	5.84
Total	14.86	16.59
Production 10^6 tons	4.345	5.454
b.o.e./ton Purch.	2.48 (72.5%)	1.97 (64.8%)
Renewables	0.94 (27.5%)	1.07 (35.2%)
Total	3.42 (100.0%)	3.04 (100.0%)

*Energy derived from biomass has been calculated on a fossil fuel replacement basis by adjusting for the lower net thermal efficiency of biomass fuels.

Forecast Additional Biomass Use in Ontario Pulp and Paper Mills

Table 4

Number of Installations	Quantity of Solid Wood Residues 10^3 tons/yr	Quantity of Spent Pulping Liquor 10^3 tons/yr	Fossil Fuel Replacement 10^6 b.o.e./yr	Estimated Capital Cost $\$10^6$
5	199		0.38	34
2		120	0.15	17
		Total	0.53	51

to fruition within the next five years, spent pulping liquor utilization will increase by slightly over four percent, and solid wood residue utilization will increase by 24 percent. These increases may be expected to "back out" about half a million barrels of oil equivalent per year. The total capital cost of these programs will be about $52 million. See Table 4.

I should add a few words of caution about biomass fueled energy systems. There are several drawbacks which must be recognized. A chemical recovery system is effective and reliable only if it is operated on a "steady state" basis. Thus where wide swings in steam demand must be dealt with, these should not be imposed on the recovery furnace. Other steam generation capacity must be available to deal with such a situation.

The "turn down" ratio of solid wood refuse fired boiler is also somewhat limited, though not as narrow as the recovery furnace. It is possible, however, to have a mixed fuel arrangement (with oil or gas) in the wood fired boiler, and take the swings on the fossil fuel burners.

Finally, I should make it clear that of the 34 mills in Ontario, steam is being generated from biomass at only 18 of them. Of the other 16, 14 are non-integrated paper or paperboard mills using pulp produced elsewhere, or recycled waste paper, as their raw material, and two have neither solid or liquid biomass available from their particular process configuration. These 17 mills must rely on fossil fuels entirely.

At least two of these 16 mills have examined the possibility of using municipal solid waste as fuel, but for a variety of reasons have not proceeded with such a program.

In summary then, the pulp and paper industry in Ontario has for the better part of 50 years utilized forest residuals for energy. Both the level of use and the technology have evolved gradually over that period and have been spurred in the last decade by the rapidly escalating fossil fuel costs. Research and development to improve the energy recovery from combustion of these residuals has been recently supported both by public and private funds. The research needs have been clearly identified by the industry and by that segment of the equipment supply sector that services the pulp and paper industry. Implementation of any significantly different new technology will be gradual, however, since the capital cost of replacing existing units is high. A typical boiler, with its auxiliaries, to burn solid wood residues can cost $30 million, while a chemical recovery furnace for the kraft industry may cost as much as $70 to $80 million. Notwithstanding these high capital costs, the fact remains that current net energy efficiency of burning solid and liquid forest residues fuels is considerably below that of fossil fuels. As the technology evolves, the more efficient units will come into use to supplant an increasing share of fossil fuels. A small number of pulp and paper mills may even become virtually energy self-sufficient by the end of the century.

Residential Wood Heating Equipment

by:
N. Fleisler,
President
Powrmatic of Canada Ltd.
Chairman – Manufacturers Council, Canadian Wood Energy Institute

Abstract

A combination of substantial price increases in the cost of traditional energy sources, plus periods of consumer concern with availability of supply, have created a large market for various types of residential wood heating equipment.

Introduction

This paper discusses the Canadian residential wood heating equipment market in terms of types of units available, market size and economics of residential wood heating.

Manufacturers

Consumer demand for residential wood heating products surfaced during the 1973-74 Middle East oil embargo. Within a relatively short time, consumer costs for home heating oil increased sevenfold. Shortages of gasoline for autos in the U.S. during the subsequent 9 year period to date also served to create consumer concern as to the availability of the fuel at all. The result was an almost overnight explosion in demand for residential wood heating equipment.

Equipment design has advanced quite rapidly during this 9 year period and the demand encouraged the growth of a sizeable manufacturing sector. The types of equipment generally available fall into the following categories.

1 Free standing wood stoves

2 Fireplace inserts

3 Combination wood-oil central warm air furnaces

4 Combination wood-electric central warm air furnaces

5 Combination wood-natural gas central warm air furnaces

6 Built in and free-standing fireplaces with heat exchangers

7 Combination wood-oil hydronic boilers

8 Wood central warm air furnaces

9 Add-on wood central warm air furnaces

10 Wood hydronic boilers

11 Add-on wood hydronic boilers

12 Cook stoves and ranges

13 Water heaters

How many manufacturers of wood burning equipment are there in Canada? Although it is not possible to give an exact figure, a recent listing by Energy Mines and Resources Canada of equipment which is approved for the Federal COSP grant programs lists the following number of manufacturers:

British Columbia	33
Alberta	1
Manitoba	10
Ontario	84
Quebec	32
Maritimes	24
U.S. and foreign	37
TOTAL	221

However, this includes several importers and distributors and does not include some manufacturers of wood burning equipment which is not presently eligible under the grant, such as inserts and certain types of fireplaces. If we exclude the imported units and add those manufacturers not on the list, the total of 221 is low approximation.

The reason I say low is that the Province of Quebec published a survey listing 34 wood equipment manufacturers, 19 of whom are not included in the 32 listed in the COSP listing. There are probably others in other Provinces and these are likely manufacturers who did not want to go to the expense of certification, which is requirement of the COSP program. Therefore, somewhere around 250 to 275 is probably a reasonably accurate guess as to the number of Canadian manufacturers.

Trade Association

The recognized trade association in Canada is the Canadian Wood Energy Institute (CWEI), headquartered in Toronto. I presently serve as chairman of the manufacturers council of CWEI. The association comprises membership in the manufacturing, retailing and distribution parts of the industry, plus chimney sweeps, approval agencies and a variety of associate members. The industry is young, includes a large number of small companies and is a rather volatile industry, battered by the ups and downs of the energy situation. For these reasons, CWEI membership comprises a rather small percentage of the total number of companies in the industry. However, a core of dedicated companies in CWEI have and are working to upgrade the industry and to maintain liaison with various certification and government agencies.

Market Size

What about market size? Unfortunately, data is not available which would provide an accurate answer. However, various surveys of the U.S. market speak of an annual market in the area of 1,500,000 units of the various types of wood heating equipment available. Taking into account our colder climate, I would "crystal ball" a guess of around 200,000 units for the Canadian market. A very strong and progressive segment of this industry is situated in Ontario. In cooperation with the Ministry of Energy of the Government of Ontario, this young industry will continue to provide a viable renewable energy source for residential heating and assist in the reduction of use of non-renewable energy. There are a large number of manufacturers, distributors and retailers of wood heat products located in Ontario providing employment directly and indirectly, such as for suppliers of steel. Wood burning tends to keep money in the local economy, as firewood is generally purchased on a local basis. Savings on reductions in use of oil and gas provide disposable income benefitting the local economy.

Statistics Canada has recently started to survey "Shipments of Solid Fuel Burning Heating Products". Unfortunately, the survey is new, does not include all manufacturers and I do not feel the figures bear any resemblance to reality at present, as evidenced by the following report for year to date to Sept. 1982:

Statistics Canada – Shipments of Solid Fuel Burning Heating Products

Statistics Canada has recently started releasing figures for the shipment of solid fuel burning appliances, following are the figures for this year up to the end of the third quarter (September 1982)

Appliance	No. of Units	Value
Heating stove, air circulating	16,586	$6,443,915
Heating stove, radiant	21,132	$7,366,405
Cooking stoves	2,819	$908,904
Free standing fireplaces	4,344	$909,812
Pre-fabricated fireplaces	13,399	$4,780,894
Fireplace inserts	6,515	$3,142,518
Furnaces, wood or coal (up to 250,000 BTU capacity)	6,193	$4,388,712
Add-on furnaces (up to 250,000 BTU capacity)	3,877	$2,123,258
Boilers for residential heating (up to 250,000 BTU capacity)	2,670	$3,035,634

Technical Trends

The technical trends have been in the following general directions:

a) More compact equipment
b) Closer clearances to combustibles
c) Improved esthetics
d) Better efficiency
e) Incorporate catalytic combustors
f) More automatic operation

A recent innovation has been a warm air furnace design by Hunter Enterprises in Orillia using wood pellets automatically fed to the unit from storage bin, similar to the coal stoker method. This affords more automatic control and less manual fuel feed.

As the demand for wood burning equipment has increased, manufacturers constantly work on product improvements. Excellent research in this area has and is being done by people such as Dr. Fernbach at Ryerson and Skip Hayden at the Canadian Combustion Research Lab. in Ottawa.

The safety aspects of wood burning equipment have come a long way in recent years and good C.S.A. and U.L.C. standards exist and are constantly updated. Both U.S. and Canadian data indicate that safety problems encountered out in the field are primarily a result of improper installations and operation of the equipment. These problems are being addressed and one example is a recent draft standard to qualify inspectors of solid fuel heating installations.

Two other technical areas concern equipment efficiencies and emissions. Much work has been and is being done in this area in North America. The W.H.A., which is the U.S. counterpart of C.W.E.I., recently published an efficiency test standard, enabling manufacturers to submit equipment to independent test labs for certification. I can tell you that the technical problems involved in calculating wood burning equipment efficiencies make efficiency calculations for oil and gas fired equipment look like child's play. The chemical content of flue gases for wood burning is extremely complicated and analysis of flue gas to determine efficiency is very difficult. Calorimeter room methods are just not practical for the average equipment manufacturer. It is probable that some reasonable simple test standard will be developed in Canada soon and it will probably include some emission standard, probably for carbon monoxide.

As the industry has grown, manufacturers, certification agencies and Federal, Provincial and Municipal authorities have been instrumental in the development of safety standards for such equipment. Standards exist for most of the equipment types listed above and such standards are in a constant state of upgrading, due to the young age of the industry. Most of the certification agencies are located in the Toronto area and their expertise in the wood heat equipment field is well recognized throughout North America. Whereas the fast, initial explosion in demand created some safety problems in the areas of equipment design, clearances to combustibles, installation and maintenance procedures and chimney problems, advances in the technology and the development of standards have by and large overcome many such problems.

C.O.S.P. Program

The C.O.S.P. grant program has had important influence on the installation of wood burning units in oil heated homes. Grants of up to $800.00 are available for eligible equipment. There are some slight modifications to eligibility in each Province. Aside from being a stimulus to the industry, the C.O.S.P. program has been instrumental in upgrading safety, as only safety certified equipment is eligible for the grant. The Toronto CWEI office can provide you with updated data on the total number of grants issued for wood burning installations on a Province by Province basis.

Economics

What about the economics of residential wood heating? As a very general estimate, home heating fuel oil at $1.00 per gallon is approximately equivalent to firewood at $125.00 per cord. You can easily calculate comparisons with natural gas and electric heat using this approximation. The figure mentioned above roughly presumes around 65% oil furnace efficiency and 50% wood heater efficiency. Firewood is available free in many areas, so the demand for wood heat equipment and the growth of the industry at the manufacturing distribution and retailing levels is more readily understood in these terms.

Although some consumers, particularly in certain rural areas use wood for 100% of their heating requirements, the majority of users are heating with wood on a partial basis for the purpose of reducing their overall annual heating costs. There has been a major growth in recent years in various hybrid systems which provide the consumer with the opportunity to use wood as a heat source while at the same time retaining the automatic use of the oil, gas or electric heating system whenever the wood heat part of the heating system is not in use. Advancements in design, control features and installation technology now provides automatic switchover from wood to the oil, gas or electric system and vice versa.

Also, although recent energy developments have dampened consumer concerns about non-renewable energy supply shortages, these concerns still exist and security of wood heat as a back up or emergency heat source is still a strong market influence. Winter power failures in heavily electrically heated areas are another buying influence for wood heat.

I want to draw your attention to an excellent published study by the Ontario government entitled "Fuelwood Consumption In Ontario". A few of the details covered are:

a) Prevalence of wood burning
b) Quantity of wood burned
c) Year began burning
d) Fuel replaced by wood
e) Fuel used for heating
f) Wood burning equipment
g) Heating equipment
h) Purpose of burning wood
i) Sources of firewood

This study provides valuable information on the wood burning situation in Ontario.

Another point not generally recognized is that during this 1973 to 1982 period, new housing design has substantially reduced the design heat loss of the residence and consequently the required size of the heating equipment. Insulation of existing residences during the same period has accomplished the same result. This trend has improved the viability of wood for residential heating by reducing wood storage requirements and increasing the effectiveness of area heating stoves. It has also made central wood heat equipment easier to use, as it is primarily hand fired.

Although the current public perception of energy shortages has calmed down, the very substantial increases in recent years in non-renewable energy costs to the consumer for space heating, plus the technology advances in wood heating equipment and safety provide a bright outlook for the continued growth of this industry.

Forest Energy Biomass Harvesting Technology Review of Selected Approaches

by:
Denis Brière
Forest Engineering Research Institute of Canada

Abstract

In spite of its recognized potential and accessibility, forest biomass for energy is a recent priority area in research and development activities. This effort is aimed at generating basic information and developing a technology to bring a larger portion of the available and potential energy biomass to a competitive level with fossil fuels. The major objective in developing forest energy biomass harvesting technology is to increase the economic availability of different sources of biomass. In an attempt to achieve this objective, various sources of energy biomas are described and some are quantified in terms of their available oven-dry-weight per year and range of recovery cost. The basic requirements and considerations for the development and selection of harvesting systems are outlined. Various recovery options for standing trees and on-the-ground logging residues are presented according to the following: (1) Evaluation of the efficiency of selected existing harvesting systems to recover forest biomass for energy; (2) Development of new harvesting systems and practices better suited to the different sources of energy biomass; and (3) Modification of conventional harvesting systems to optimize the recovery of forest biomass for both conventional products and energy biomass. The perspective of forest energy biomass options within the forest management framework is briefly outlined.

Introduction

Forest biomass is a form of stored solar energy fixed by photosynthesis and held briefly for different uses. Forests, which cover about a tenth of the earth's surface, fix almost half of the biosphere's total energy. The different forest ecosystems are composed of many species arranged in a structure that apportions the available solar energy as effectively as possible

Various sources of forest biomass and their potential for generating energy are receiving considerable attention due to our dependence on fossil fuel – an increasingly unreliable and cost-unpredictable source of energy which is the cornerstone of the Canadian economy.

Sources of renewable energy from the omnipresent forest biomass in Canada are being rediscovered. The unutilized forest biomass generated by the average annual harvest of 156 million m^3 by the Canadian forest industry, represents by itself a potential source of energy equivalent to 15% of the total current primary energy needs for Canada, or in more tangible terms, it is equivalent, with a combustion process efficiency of 60%, to some 20 billion liters of fuel oil.

By definition, the unused forest residues are what is left after valuable products have been removed by harvesting or manufacturing processes. It has been called slash, unmerchantable stems, residual, stagnated or damaged stands, cull logs, tops and branches, foliage and roots by the logger; and slabs, edgings, chips, sawdust, bark, hog fuel, waste pulp liquor by the mill manager. By its nature and the volume generated, "forest residues" have been viewed more as a problem to be dealt with than as an opportunity to be exploited. Only during the past few years have forest residues been elevated to the status of a renewable resource capable of producing energy.

Residues from pulp and paper mills and the solid wood manufacturing industries are generally the most inexpensive and readily available source of biomass for energy. In fact, the Canadian forest industry consumes 280 PJ/year of mill residues such as pulp liquor and hog fuel. Some of this forest biomass is not yet utilized but the surplus is regionally concentrated, making the supply-demand balance negative in certain regions. For example, some 55% of the available mill "residues" for additional energy generation are found in British Columbia. According to recent studies, it is expected that by 1985 many regions in Eastern Canada will experience a shortage of mill "residues". We must therefore turn to other forms of forest biomass for energy such as logging "residues", unutilized natural stands of mature trees, damaged or stagnated forests and eventually to biomass from energy plantations.

The encouraging gross inventory figures, for the available forest biomass located within or outside current wood harvesting areas, do not imply that the entire biomass resource is economically or physically available. Nevertheless, the figures indicate that with improved harvesting technology, the currently unused biomass could provide a substantial amount of wood fibre with no added drain on the timber supply.

The recovery, processing and transportation of forest biomass for energy is a recent preoccupation. The conventional harvesting systems have to be either adapted or modified, and new approaches and concepts must be developed to suit the physical characteristics, distribution and terrain conditions of the various sources of energy biomass within or outside existing wood harvesting operations. Options are discussed according to the following:

- Evaluation of the efficiency of selected existing harvesting systems to recover forest biomass for energy.
- Development of new harvesting systems and practices better suited to the different sources of energy biomass.
- Modification of conventional harvesting systems to optimize the recovery of forest biomass for both conventional products and energy biomass.

Sources of Forest Biomass

Aside from existing mill residues, the following sources of energy biomass are usually recognized:

1 Source: Economically accessible stands of commercial and non-commercial species located within current wood harvesting areas.

Nature: Tops, branches, broken stems and thinnings left at the stump, roadside, landing or sortyard area. Residual trees and stumps.

2 Source: Economically accessible non-commercial species located within and outside current wood harvesting areas.

Nature: Unutilized natural stands of mature trees (aspen) or stagnated brushwood. Windfalls, diseased and fire-killed stands.

3 Source: Energy forests, consisting of short-rotation coppice or planted species.

Nature: Small diameter and short trees.

Estimating existing forest biomass potential for energy generation in Canada is illustrated by Figure 1. Mill residues are already an economical source of energy within the forest products industry. In 1977, 280 PJ were generated from pulp liquor (188 PJ) and hog fuel (92 PJ or 4.6 million ODt). The available mill residues are concentrated in British Columbia, having 55% of the total national availability. By contrast, certain regions in the province of Québec are already experiencing a deficit of mill residues which must be compensated by imports from the surrounding regions. Also, there is a demand from communities and other industry sectors for thermal and mechanical energy, solid, liquid or gaseous prepared fuels or industrial chemicals.

According to recent studies, the expected 1985 demand for mill residues in many regions will drain the projected supply. This led to the generally accepted trend that next to mill residues, the logging residues are the most economically accessible biomass resource, assuming no major changes in the conventional logging methods. Figure 1 shows the potential of logging residues representing 24 million ODt/year. This figure is conservative, since it excludes the available merchantable logging residues.

The recovery cost of logging residues is related to the nature of the different energy biomass sources as already described. A variety of harvesting systems are under development to match the size, location and distribution of the unutilized biomass over a range of terrain conditions. Logging residues are catagorized in Figure 2 according to their relative economic availability. Table 1 gives an example of the amount of biomass left in the stump area after different logging methods in a black spruce forest type.

Stand conversion and salvage of damaged forest stands as illustrated by Figure 1 represent some 40 million ODt per year of available biomass. The added value of converting these stands to more desirable species composition

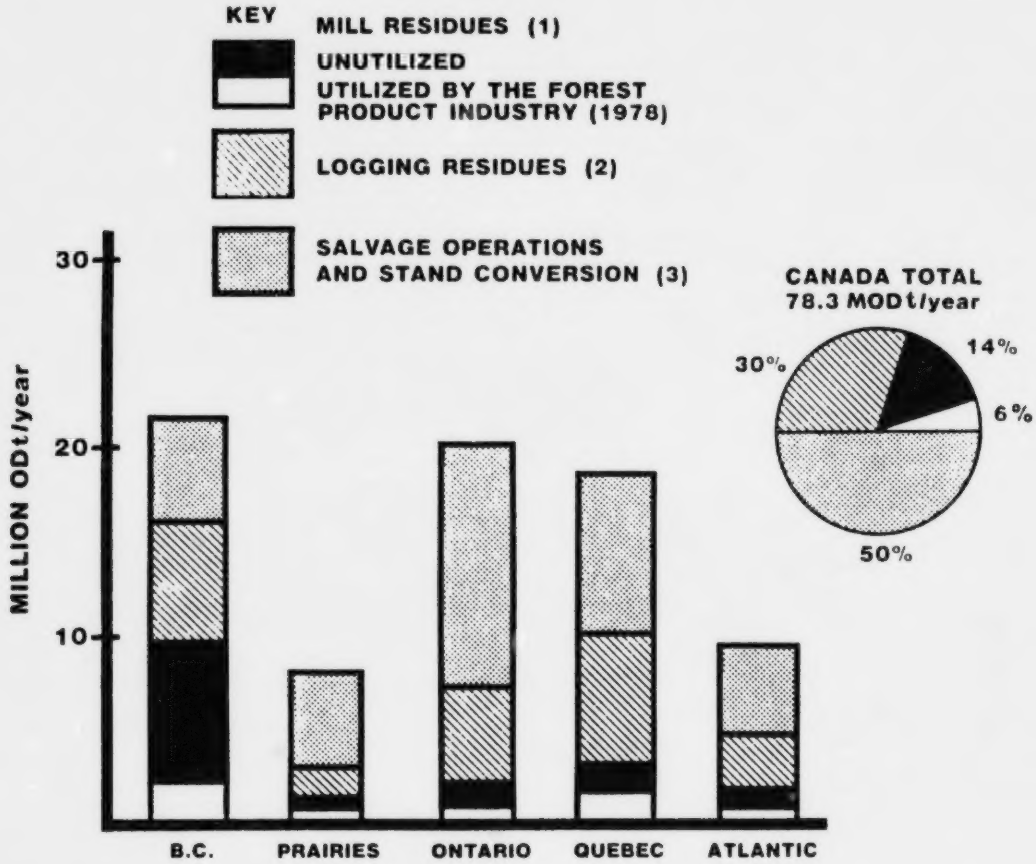
Logging Residues Following Three Different Logging Methods in a Black Spruce Forest Type

Table 1

LOGGING METHOD	TYPE OF RESIDUES TOPS	Branches	Chunkwood	Total
	(oven-dry tonnes/ha)			
Full Tree	1.2	3.2	16.3	20.7
Tree Length	26.2	11.6	16.0	53.8
Shortwood	11.1	22.0	37.6	70.7

Potential Forest Biomass for Energy Generation in Canada from Selected Sources

figure 1



Sources: INTERGROUP (1982)
LOVE P. (1980)

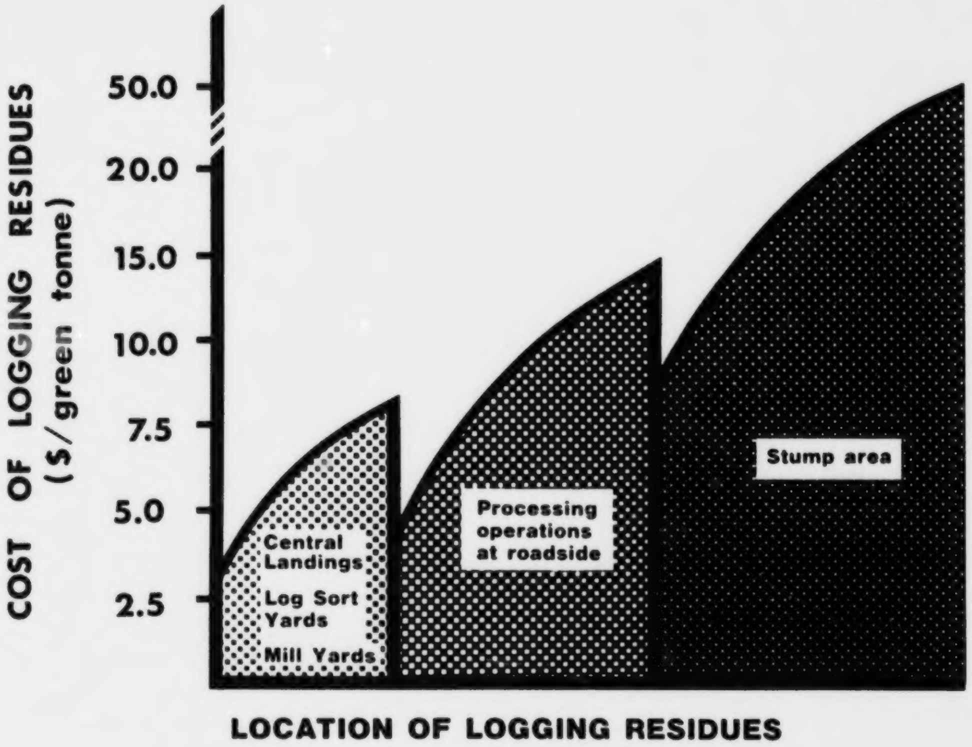
(1) MILL RESIDUES: Bark, sawdust and shavings derived from conventional forest product processing. Sawmill chips are excluded assuming their use for pulp production.

(2) LOGGING RESIDUES: This is a conservative figure since it excludes merchantable logging residues.

(3) SALVAGE: Killed or damaged forest stands
STAND CONVERSION: Stands where rehabilitation and regeneration is highly desirable.

Logging Residues and their Relative Economic Availability with Existing Harvesting Technology

figure 2



NOTE: The cost increases within each category represent the recovery, processing and transportation cost (less than or equal to 100 km) variations related to the nature and distribution of the residues left by various logging operations.

within proximity of processing centres is not addressed here, but this opportunity for forest renewal must be recognized as an important integral part of utilizing forest biomass for energy.

Harvesting Techniques and Systems

The wide range of energy biomass sources residues in the absence of specifications of wood for energy. Any portion of a tree, any species and size can be utilized. The recovery of logging residues alone could double wood fibre utilization within the existing forest land base. Despite the huge amount of raw material available, the development of harvesting systems is subject to the following considerations and requirements:

- The harvesting system must provide raw material at competitive cost. To achieve this objective, the recovery system must be designed for a specific and clearly defined source of biomass, taking into consideration the surrounding biophysical conditions and existing wood harvesting operations.
- The delivered biomass must be clean with a range of moisture content, density and particle size distribution suitable for various conversion systems.
- The option of energy biomass must be integrated within the framework of forest management. For example, the harvesting system must be designed to foster forest renewal in terms of site preparation, following logging residues recovery, stand conversion or salvage operations.

Within its comprehensive program for the development of energy biomass harvesting technology, FERIC has developed a system presented in Figure 3 to cope with different variables such as the nature of energy biomass; the recovery and processing requirements; the optimization of secondary transportation; and the conversion to energy at various locations with other functions such as forwarding and primary processing or compaction.

Research and development in biomass harvesting systems has taken three directions:

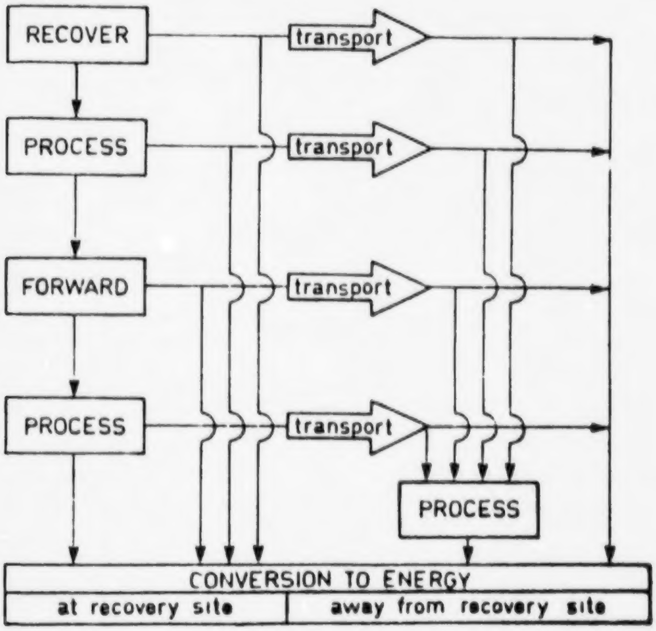
1 Evaluation of the efficiency of selected existing harvesting systems to recover forest biomass for energy.

2 Development of new harvesting systems and practices better suited to the different sources of energy biomass.

3 Modification of conventional harvesting systems to optimize the recovery of forest biomass for both conventional and energy biomass products.

From Biomass to Energy

figure 3



Evaluation of the Efficiency of Selected Existing Harvesting Systems to Recover Forest Biomass for Energy

Recovery of standing trees

Historically, conventional logging systems have evolved to accommodate a wider mix of material size and quality. Systems are already designed to handle smaller diameter trees of natural and second growth stands.

A number of case studies were carried out to evaluate the performance of conventional logging equipment to recover standing trees for energy biomass. Generally, the results of these tests indicate that energy biomass in the form of standing trees can be extracted and processed into chips at roadside for less than $20.00 per green tonne. Harvesting of hardwood stands for energy can be profitable with the greatest success being achieved in stands with the larger diameter trees. A number of case studies are presented in Appendix A.

The results of these studies are very valuable in terms of comparing different harvesting systems to recover standing trees of different sizes and densities in various terrain conditions. Areas of improvement can be identified and efficiency objectives stated for any further equipment development.

The potential of any equipment recently commercialized must also be evaluated. For example, the circular saw felling head with accumulator developed by FERIC and commercialized in 1981 is a promising approach for the recovery of a wide range of tree sizes, particularly for multi-stem felling of small trees.

Recovery of on-the-ground logging residues

Residues left in the stump area represent a recovery problem especially for the small diameter material, requiring a large number of trips over the logged area to skid a small volume per load. The cost of ground skidding related to the volume of pieces is presented in Appendix B, along with case studies and cost of cable yarding related to average piece size to be recovered. Cost of skidding or yarding of logging residues to roadside is reported to have a range of $10 – $40 per green tonne.

From the revised studies it is obvious that, in many instances, present harvesting systems and equipment are not suitable to economically recover on-the-ground logging residues in the stump area, mainly because of the size and distribution of the logging residues causing an inefficient use of the machinery.

Development of New Harvesting Systems and Practices Better Suited to the Different Sources of Energy Biomass

Recovery of standing trees

New harvesting machines have been designed to accommodate the recovery, processing and forwarding of stagnated stands composed of small diameter, unmerchantable species for energy biomass.

These machines are either at the experimental prototype or the precommercial level – none have been fully proven commercially.

The basic premises and objectives underlying the development of these machines are:

- Harvesting of small trees for fuel based on full tree logging methods in which delimbing is abandoned completely.
- Large-scale harvesting equipment must handle small-sized trees as a mass at all stages of harvesting, as opposed to the single tree approach.
- A continuously moving machine is needed to perform felling followed by processing and forwarding, or on-site bunching or windrowing of the energy biomass.

Harvesting machines designed to meet the above requirements are under development. The Georgia Pacific brush harvester being developed in Arkansas, U.S.A., to harvest small standing biomass suitable for use as boiler fuel fells, collects and chips in an on-board hopper. The U.S. Forest Service developed a biomass harvester from a concept proposed by P. Koch and D. W. McKenzie; and the Finnish Forest Research Institute developed the Pallari swath harvester.

There is a general tendency to chip the gathered material immediately after its recovery. Experience suggests that the economics of chipping in the stump area suffer greatly from both organizational and mechanical delays added to the high energy requirements of chipping operations.

This was identified by FERIC as being an area of potential improvement through research and development. It is after testing and evaluating energy requirements of four types of biomass reducing equipment like chippers, hammermills and crushers that the Roll Splitter was selected as an approach to be pursued. This approach consists of two pairs of rollers, one to split and crush the woody biomass, and the other to squeeze out the water; an important consideration in preparing woody biomass for transportation and conversion to energy. The resulting material is long and flexible splinters suitable for load compaction and densification of the biomass in the form of bales. This compacted material would permit the utilization of the full payload capacity in transportation and give more flexibility in terms of storage and drying of the energy biomass before actual conversion.

The Roll Splitter concept illustrated in Figure 4 is being completed under the auspices of ENFOR (Energy from the Forest program). Plans for next year will focus on the compaction aspect of the system.

Recovery of on-the-ground logging residues

The location of processing sites (delimbing, topping and slashing) is a determining factor as illustrated by Figure 2 in selecting the approach for recovering and processing residues from a specific wood harvesting operation.

The recovery of logging residues left on the forest floor is a problem which requires a new approach. These residues have a wide range of size and shape, and are spread over extensive areas. They are bulky and difficult to handle with a moisture content of 45 to 60 percent. Their nature and quantity varies with the type and composition of the stand harvested and the logging method used (see Table 1).

In searching for a suitable approach FERIC, as a participant in Canada's ENFOR (Engery from the Forest) program, came across a concept offering the features considered desirable for the recovery of logging residues on gently sloping terrain: low energy requirement; ability to pick-up logging residue without prior bunching, reduce it to a form suitable for bulk handling and deliver the processed material to roadside. Figure 5 illustrates the configuration of the RECUFOR.

The basic principle consists of a rotor 1 m in diameter and 2 m wide, equipped with 15 curved teeth having sharp bevelled edges and placed in 3 rows of 5. These teeth pick-up the residues and shear them against fixed blades located at the back of the rotor. Most of the residues in log form are sheared to lengths about equal to the spacing between the fixed blades, in this case being 38 cm. Branches are broken and macerated. The processed material is conveyed into a self unloading container to be forwarded at roadside.

Field testing of the experimental prototype was conducted during the summer of 1982. The RECUFOR prototype performed to expectations and the basic concept has been successfully verified. The results of these tests are currently being used to optimize the design of the recovery, processing and conveying system of this energy biomass harvesting machine developed specifically for on-the-ground logging residues.

Following the ongoing modifications, it is expected that the RECUFOR will cover .5 hectare per hour and collect the logging residues, excluding stumps. Operating in conditions following the shortwood logging method, as described in Table 1, the RECUFOR should deliver processed material to roadside at the rate of 40-50 green tonnes per hour, at a cost of less than $8 per green tonne. Other applications of the RECUFOR concept such as the recovery of blown down and fire killed forests remain to be investigated.

In situations where steep slopes make ground operations impossible, the high cost of cable yarding precludes the recovery of pieces averaging less than 0.4 or 0.6 m^3 making these economically inaccessible with existing equipment. There is a trend toward the development of small cable yarding systems in an attempt to reduce the cost of recovering small pieces.

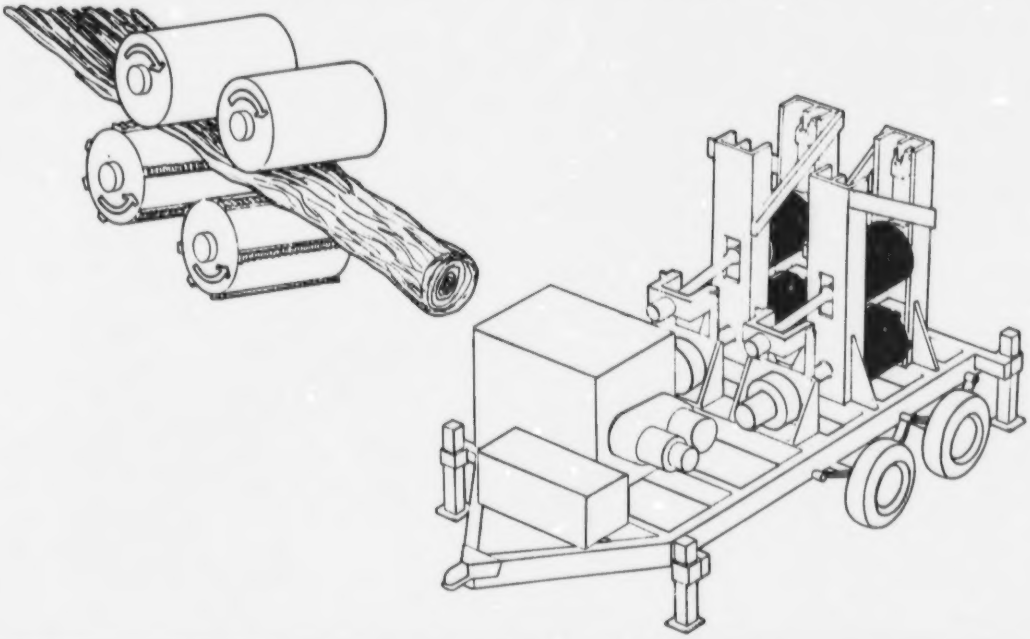
This second pass approach for recovering logging residues may be questionned as to its economics when compared with methods using full tree removal (with branches and tops). According to Wikston and Prins (1980), the retrieval of forest biomass after normal logging operations provides more options in adapting retrieval of forest biomass to demand. It is also easier to apply a selective recovery with respect to site sensitivity. Thus, there are reasons to believe that the recovery of logging residues for still some time may be carried out as a separate harvesting operation.

Modification of Conventional Harvesting Systems to Optimize the Recovery of Forest Biomass for Both Conventional and Energy Biomass Products

Recovery of standing trees

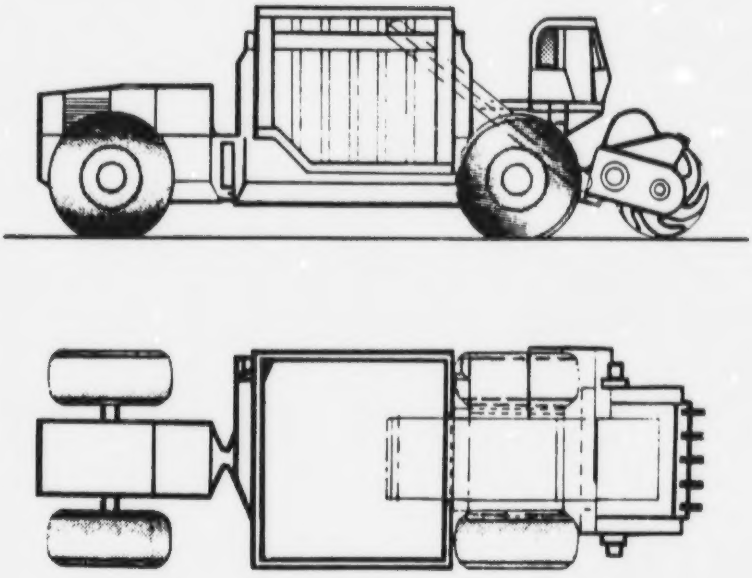
Within the forest industry, there is already a trend to develop harvesting systems for smaller diameter trees, especially for pulp production. Examples are the development of accumulating felling heads, twin delimber heads and the work

Experimental prototype of the Roll Splitter. figure 4



FERIC RECUFOR* figure 5

*Registered trademark



on multi-stem delimbing at FERIC.

The forest stand even for conventional products is more and more looked upon as a mass rather than individual stems to be handled separately. The option of energy biomass and more specifically the need for stand conversion should accelerate the development of harvesting systems for small sized standing trees.

Recovery of logging residues

According to recent studies from Canada (Wiksten and Prins, 1980), Sweden (Larsson, 1982) and U.S.A. (Stuart et al, 1981) a general conclusion reached concerning the recovery of logging residues is that branches and tops, to be recovered efficiently and economically, should be brought to a processing site when still attached to the tree. This implies that the retrieval of the forest biomass be done simultaneously with conventional logging operations.

FERIC is developing a logging residue processor to recover the biomass generated by delimbers at roadside as part of full tree logging which is gaining popularity in Canada. This wood harvesting system consists of bringing full trees to roadside and use a sliding boom delimber to remove branches and tops, which represent 25% of the harvested trees.

Residue recovery and processing operations can be integrated with full tree logging for optimum utilization of wood fibre and economies of scale through a merchandiser type of landing where trees can be sorted and processed according to end products, including energy. Most of the hardware for such an approach is available or could be developed from existing technology within a reasonable period of time. Site specific studies indicate that residues recovered from such processing centres could not only make them energy self-sufficient but also indicate the potential to export excess energy to nearby camps, communities or other industry sectors.

The general arrangement of an integrated complex was recently brought to FERIC by Logging Development Corporation. Figure 6 illustrates the general design proposed for the recovery and preparation of biomass feedstocks. This project is described in the ENFOR (Energy from the Forest) report C-253.

Concerning the harvesting equipment for full tree logging, it is desirable to use forwarders that can carry the load to roadside. This would eliminate the contamination of trees dragged on the mineral soil, causing unnecessary problems in pulping equipment and boilers. Also, the use of such forwarders would optimize the recovery of tops and branches, especially when compared to the biomass broken off and left on site when skidding frozen trees.

Conclusion

Forest biomass for energy generation is now being utilized in Canada and the potential for further commitments in the form of logging residues, stand conversion and salvage operations can and is being matched with the development of forest energy biomass harvesting technology.

The increased opportunities for forest renewal, energy self-sufficiency and the creation of new forest products and markets associated with the implementation of the energy biomass option is yet to be fully evaluated and appreciated within the forest management framework. Inherent to the energy biomass option is the added value of associated activities like site preparation, stand conversion, salvage operations and energy plantations resulting in an increased wood fibre production and utilization without the need for enlarging the existing land base.

An additional forest product such as energy biomass for a variety of markets would be a contributing factor to buffer the well known cyclical nature of the forest based industry, a major contributor to the general Canadian economy.

The revised approaches and systems for harvesting energy biomass stress the need for a continuing effort in research and development. To that effect, FERIC is participating as the managing agent in two projects of the International Energy Agency dealing with the recovery, transportation and preparation of forest biomass for optimal conversion to energy. Through these projects FERIC is extending its research and development activities at the international level, and has access to a broader base of information, technical data and experience in the utilization of forest biomass for energy.

References

1 INTER GROUP CONSULTING ECONOMICS LTD., Availability and Cost of Forest Biomass in Canada. ENFOR Project P-224(1). 1982.

2 LOVE, P., Biomass Energy in Canada. It's Potential Contribution to Future Energy Supply. Prepared for Energy, Mines and Resources Canada, Ottawa. 1980.

3 WIKSTEN, N.A. and PRINS, P.G., Cost Estimates of Forest Biomass Delivered at the Energy Conversion Plant. ENFOR Project P-19.

4 LARSSON, M., Harvesting and Transportation of Forest-Energy Wood in Sweeden. Skogsarbeten, Results No. 3. 1982.

5 STUART, W.B., PORTER, C.D., WALBRIDGE, T.A. and ODERWALD, R.G., Economics of Modifying Harvesting Systems to Recover Energy Wood. Forest Prod. J. 31(8): 37-42. 1981.

6 WILTON, W.G. and DUFFET, W.P., Whole Tree Chipping for Hogged Fuel in Newfoundland. Abitibi-Price Inc. 1980.

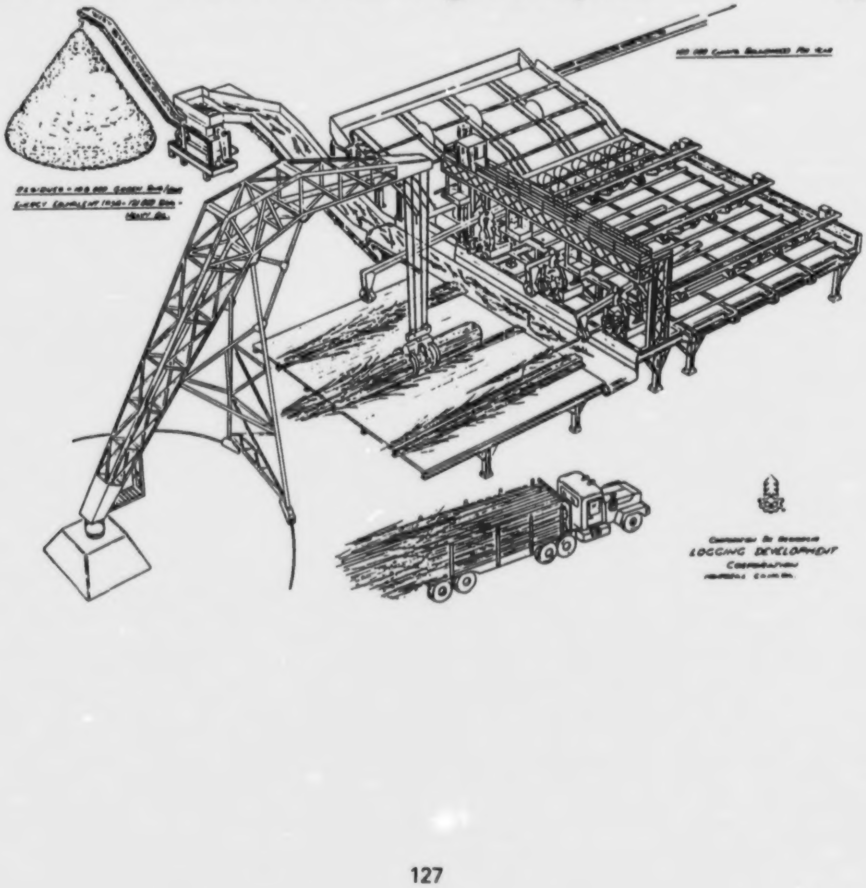
7 CHISHOLM, B.S. and van RAALTE, G.D., Biomass Harvesting and Chipping in a Tolerant Hardwood Stand in Central New Brunswick. Valley Forest Products Ltd. 1980.

8 AROLA, R.A. and MIYATA, E.S., Harvesting Wood for Energy. USDA Forest Service Research Paper NC-200. 1981.

9 WITHYCOMBE, R.P., Estimating Costs of Collecting and Transporting Forest Residues in the Northern Rocky Mountain Region. USDA For. Serv. Gen. Tech. Rep. INT-81. 1982.

Central Full-tree Processing Complex

figure 6



Full Tree Biomass Recovery (Removal of all trees)

Appendix A.1

Description of Recovery Area

Stand: 75-year old white birch, with some black spruce and large scattered trembling aspen and balsam fir.
Topography: Fairly flat terrain; partially saturated stone-free clay loam.
Tree Size: Majority below merchantable; mean diameter 6 cm and above dbh is 16.2 cm.
Stand Density: <6 cm dbh=8342 trees/ha; ≥6 cm dbh=1214 trees/ha
Pre-recovery Biomass Volume: 174 green tonnes (101 ODt) per ha
Biomass Recovered: 155 green tonnes (91 ODt) per ha
Moisture Content: 41 percent
Transportation Distance: 15 km

Summary of Recovery Operations

Operation	Total Volume Recovered (green tonnes)	Productivity (green tonnes per hour)	Cost in 1979 Can. $ Per green tonne	Per GJ[4]
Extraction[1]	2050	5.8- 7.5	5.82	.501
Processing[2]	2050	17.6-22.5	3.20	.279
Transportation[3]	2050	13.9 loads/day (8.6 tonnes/load)	3.49	.300
Total	2050		12.51	.810

[1] Manual felling with power saws; extraction with rubber-tired skidders

[2] With Morbark Model 22 Chipharvester

[3] With modified dump trucks (9.1 tonne capacity)

[4] Based on as-fired heating value of chips when delivered to conversion site. 1 Gj=1 Gigajoule=10^9 Joules=0.948 x 10^6 Btu

Source: Whole-Tree Chipping for Hogged Fuel in Newfoundland – W.C. Wilton and W.P. Duffett. Abitibi-Price Inc. 1980.

Full Tree Biomass Recovery (Removal of all trees)

Appendix A.2

Description of Recovery Area

Stand: 60-year old hardwood, mainly white birch with some trembling aspen and black spruce.
Topography: Gently rolling, stone-free, well-drained clay loams with scattered boulders.
Tree Size: Below merchantable size for conventional solid wood harvesting. Average diameter above 6 cm dbh=9.3 cm.
Stand Density: <6 cm dbh=1452 trees/ha; ≥6 cm dbh=3314 trees/ha
Pre-recovery Biomass Volume: 144 green tonnes (82 ODt) per ha
Biomass Recovered: 134 green tonnes (77 ODt) per ha
Moisture Content: 43 percent
Transportation Distance: 3 km

Summary of Recovery Operations

Operation	Total Volume Recovered (green tonnes)	Productivity (green tonnes per hour)	Cost in 1979 Can. $ Per green tonne	Per GJ[4]
Extraction[1]	3100	2.3- 6.2	8.53	0.74
Processing[2]	3100	16.1-19.2	4.65	0.40
Transportation[3]	3100	9.6 loads/day (8.7 tonnes/load)	3.52	0.30
Total	3100		16.70	1.44

[1] Manual felling with power saws; extraction with rubber-tired skidders

[2] With Morbark Model 22 Chipharvester

[3] With modified dump trucks (9.1 tonne capacity)

[4] Based on as-fired heating value of chips when delivered to conversion site. 1 Gj=1 Gigajoule=10^9 Joules=0.948 x 10^6 Btu

Source: Whole-Tree Chipping for Hogged Fuel in Newfoundland – W.C. Wilton and W.P. Duffett. Abitibi-Price Inc. 1980.

Full Tree Biomass Recovery (fully mechanized)

Appendix A.3

Stand: Fire origin, 60-year old mixedwood/tolerant hardwoods. Beech, red, striped and sugar maple, yellow and white birch, poplar and red spruce.
Topography: Gently rolling.
Tree Size: Average 22.4 cm dbh with number of small diameter stems.

Summary of Recovery Operations

	AREA 1		AREA 2		AREA 3	
Operations	Total Volume Recovered (green tonnes)	Cost in 1980 Canadian $ (per green tonne)	Total Volume Recovered (green tonnes)	Cost in 1980 Canadian $ (per green tonne)	Total Volume Recovered (green tonnes)	Cost in 1980 Canadian $ (per green tonne)
Extraction[1]	420	3.76	424	4.26	368	4.29
Processing[2]	400	3.67	404	4.00	348	3.70
Total		7.43		8.26		7.99

1 With Koehring Feller-Forwarder

2 Morbark Model 22 Chipharvester

In area 1, felling was done to normal standards, while in areas 2 and 3, the KFF operation was followed by a cleaning-up with power saws and skidders to recover as much as possible of the residual material. This volume thus recovered represented 2 percent of the total in one case and 10 in the other.

Source: Biomass Harvesting and Chipping in a Tolerant Hardwood Stand in Central New Brunswick—B.S. Chisholm and G.D. van Raalte. Valley Forest Products Ltd. 1980.

Full Tree Biomass Recovery (Removal of low-value hardwoods for stand conversion)

Appendix A.4

Description of Recovery Area

Stand: Low-value northern hardwoods— red and sugar maple, yellow birch, cherry and some oak, white pine and hemlock. Stand about 50 years old.
Topography: Flat; sandy loam.
Tree Size: 2.5-30.5 cm dbh, most under 25.5 cm
Stand Density: 1993 trees/ha
Biomass Recovered: 183 green tonnes/ha
Moisture Content: ~40 percent
Transportation Distance: 35 km

Summary of Recovery Operations

Operation	Total Volume Recovered (green tonnes)	Productivity (green tonnes per hour)	Cost in 1979 U.S. $	
			Per green tonne	Per GJ[4]
Extraction[1]	~1630	18.0	3.34	0.27
Processing[2]	1346	40.0	2.33	0.19
Transportation[3]	1346	—	2.61	0.21
Total	1346		8.28	0.67

[1] Drott 40 LC feller/bunchers with accumulator shear; 1 John Deere 740 grapple skidder

[2] 1 Morbark Model 22 Chipharvester; 1 Pettibone PM 850 chain flail

[3] 13 chip vans with 4 truck tractors

[4] Based on as-fired heating value of chips 1 GJ=1 Gigajoule=10^9 Joules=0.948 x 10^6 Btu

Source: Harvesting Wood for Energy—Rodger A. Arola and Edwin A. Miyata. USDA Forest Service Research Paper NC-200.

Cost of Ground Skidding (In 1977 US $ per green tonne)

Appendix B.1

VOLUME PER PIECE[1] (m^3)	ONE-WAY SKIDDING DISTANCE (meters)											
	15	30	46	61	91	122	152	183	244	305	610	914
0.01	55.4	57.3	59.2	61.0	64.8	68.6	72.4	76.2	83.8	91.4	129.3	167.2
0.03	27.7	28.7	25.2	30.5	32.4	34.3	36.2	38.1	41.9	45.7	64.7	83.6
0.04	18.5	19.1	19.7	20.3	21.6	22.9	24.1	25.4	27.9	30.5	43.1	55.7
0.06	13.8	14.3	14.8	15.2	16.2	17.1	18.1	19.0	20.9	22.9	32.3	41.8
0.08	9.2	9.7	9.9	10.2	10.8	11.4	12.0	12.7	14.0	15.2	21.6	27.9
0.11	6.9	7.2	7.4	7.7	8.1	8.6	9.0	9.5	10.5	11.4	16.2	20.9
0.14	5.6	5.7	5.9	6.0	6.5	6.9	7.2	7.6	8.4	9.1	12.9	16.7
0.28	2.8	2.9	2.9	3.0	3.3	3.4	3.7	3.8	4.2	4.6	6.5	8.4
0.42 or over	1.8	1.9	2.0	2.0	2.2	2.3	2.4	2.6	2.8	3.0	4.3	5.6

[1] Volume per load assumes ten pieces per load to a maximum of 4.2 m^3

Source: Estimating Costs of Collecting and Transporting Forest Residues in Northern Rocky Mountain Region. R.P. Withycombe. USDA. 1982.

Retrieval of Logging Residues

Appendix B.2

Stand: Lowland softwood — softwoods dominant
Region: Boreal forest region
Previous Logging: Manual felling with power saws; extraction with rubber-tired skidder
Biomass (logging residues): 42 green tonnes per hectare
Moisture Content: 50% (assumed)
Average Volume per Piece: 0.04% m^3 (limbs are retrieved only when attached to parts of the bole)

EQUIPMENT	ALTERNATIVE 1 MEDIUM SKIDDED[1]			ALTERNATIVE 2 SMALL FORWARDER[2]		
	Productivity (green tonnes/hour	Cost in 1980 Can. $ Per green tonne	Per GJ[4]	Productivity (green tonnes/hour)	Cost in 1980 Can. $ Per green tonne	Per GJ[4]
Recovery[3]	0.64	37.50	3.795	1.08	28.50	2.884
Chipping	6.00	5.60	0.567	6.00	5.60	0.567
Transportation (100 km)		3.40	0.344		3.40	0.344
Total		46.50	4.706		37.50	3.795

[1] Medium (small) wheeled skidder 75 hp with winch and chokers; one man operation. Skids pieces or bunches of pieces of varying length.

[2] Small wheeled forwarder with articulated, frame-steered, four-wheel drive chassis, centre mounted, articulated boom and grapple, load capacity 5 m^3.

[3] Average forwarding distance: 250 m.

[4] 1 GJ = 1 Gigajoule = 10^9 Joules = 0.948 x 10^6 Btu.

Source: Cost Estimates of Forest Biomass Delivered at the Energy Conversion Plant. N.A. Wiksten and P.G. Prins. ENFOR Project P-19. 1980.

Retrieval of Logging Residues

Appendix B.3

Stand: Mixed wood upland — softwood dominant
Previous Logging: Koehring shortwood harvester
Biomass (logging residues): 118 green tonnes per hectare
Moisture Content: 50% (assumed)
Average Volume per Piece: 0.15 m³ (limbs are retrieved only when attached to parts of the bole)

EQUIPMENT	ALTERNATIVE 1 MEDIUM SKIDDED[1]			ALTERNATIVE 2 SMALL FORWARDER[2]		
	Productivity (green tonnes/hour	Cost in 1980 Can. $		Productivity (green tonnes/hour)	Cost in 1980 Can. $	
		Per green tonne	Per GJ[4]		Per green tonne	Per GJ[4]
Recovery[3]	2.48	9.50	0.962	3.46	9.00	0.911
Chipping	6.00	5.60	0.567	6.00	5.60	0.567
Transportation (100 km)		3.40	0.344		3.40	0.344
Total		18.50	1.873		18.00	1.822

[1] Medium (small) wheeled skidder 75 hp with winch and chokers; one man operation. Skids pieces or bunches of pieces of varying length.

[2] Small wheeled forwarder with articulated, frame-steered, four-wheel drive chassis, centre mounted, articulated boom and grapple, load capacity 5 m³.

[3] Average forwarding distance: 250 m.

[4] 1 GJ=1 Gigajoule=10^9 Joules=0.948 x 10^6 Btu.

Source: Cost Estimates of Forest Biomass Delivered at the Energy Conversion Plant. N.A. Wiksten and P.G. Prins. ENFOR Project P-19. 1980.

Cost of Cable Yarding[1]

Appendix B.4

Average Piece Size (m³)	Yarding Cost/ Green Tonne (in 1981 US $)
0.01	339.0
0.03	172.0
0.04	115.0
0.06	87.0
0.08	59.0
0.11	45.0
0.14	36.0
0.28	19.0
0.42	13.6
0.57	11.0
0.71	9.4
0.85	8.5
1.13	7.6
1.42	7.0
1.70	6.2
1.98	5.5
2.26	4.9
2.55	4.5
2.83	4.1

[1] For yarding distances of 300 meters to no more than 600 meters add 20% to the figures.

Source: Estimating Costs of Collecting and Transporting Forest Residues in the Northern Rocky Mountain Region. R.P. Withycombe. USDA. 1982.

Hybrid Poplar Energy Plantations in Ontario

by:
H.W. Anderson[1]
L. Zsuffa[2]

Abstract

Energy plantations are being considered in several countries for achieving greater energy independence. The short-rotation, fast-growing hardwoods prgramme of Ontario attempts to maximize the efficient production of energy through optimization of the growth of selected plant crops.

Bioecological factors, genetic improvement, cultural treatments and conversion methods all have important effects on output measured in terms of biomass yield, quality energy content and production economies.

Intensively-managed short-rotation plantations of genetically improved fast growing trees can make significant contributions to energy supplies. Some aspects of the Ontario programme are ready for implementation but research and development must continue to improve these technologies.

Introduction

Solar radiation is perhaps the most abundant yet elusive form of available energy. Fortunately, living plants can photosynthetically convert and store a portion of this energy as dry matter or biomass. The biomass energy thus stored annually on a global basis is equivalent to 10 times the world's annual energy need. It has been estimated that the present standing biomass, which consists mainly of forests, approximates the total amount of proven fuel reserves below ground.[11]

Forests have been utilized for and even dedicated to fuel production since the ancestral discovery of fire; and until the 19th century, the world relied mainly on wood for cooking and heating. Even today, about half of the world population relies on wood for its cooking and about one-half of all trees harvested are utilized for these necessities of life. In some developing countries, biomass constitutes 90% of the energy need and overuse of biomass resources is showing serious, potentially long term consequences.[19]

In an era dedicated to energy conservation, today's expanding technology requires new and more effective uses for forest biomass energy. In Canada, less than half of the annual forest biomass growth is utilized yearly, and of this only 3% is used as fuel.[6] Utilization practices in Ontario are such that for every tonne of harvested forest which is utilized, another tonne is left on the ground as residue. Recovery and transportation costs and market availability often limit the attractiveness of this material as an energy resource.

Recently, man-made forests or plantations grown in intensive culture, close to markets, on very short rotations, and designed for a variety of uses including energy, have shown great promise in Ontario and elsewhere.[25] In 1980, the Ontario Ministry of Energy announced a 15-year programme to develop "energy from waste".[16] The target for 1995 is to produce 35% of Ontario's energy need of 840 million barrels of oil equivalent (BOE) within its jurisdiction. The renewable energy segment (excluding hydroelectric power) will supply 5% of demand. Of this, 1.8% of demand will derive collectively from mill residue (0.1%), bush residues (1.0%) and energy plantations (0.7% or 5.9 million BOE).

With approximately one-half million hectares of currently underutilized land occurring in eastern Ontario, the target for energy plantations of hybrid poplar is to produce 2.5 million dry tonnes of wood feedstock annually by 1995. Along with industrial and logging residues, the material will be directed towards institutions such as Grenville Christian College in Brockville for use in fully-automated wood-burning systems.

Eventually, such biomass will be used to co-generate process steam and electricity and to produce more refined energy materials such as fuel pellets and synthetic liquid fuels. Because of its versatility, however, portions of hybrid poplar biomass could be equally converted to animal feed, fibre products or construction materials should markets develop or alternative energy competition arise.

[1,2] Research Scientists, Ministry of Natural Resources, Ontario Tree Improvement and Forest Biomass Institute, Maple, Ontario, Canada L0J 1E0.

The Nature of Energy Plantations

Natural forests and wood residues are often not available in significant quantities for energy conversion in areas where population and industries need them; however, land may be available for biomass production in man-made forests. The concept of the "energy plantation" was suggested by Szego and Kemp in 1973[21] in response to concerns about the supply of imported oil. Previous proposals to use "mini rotations",[20] silage forests[15] and "complete tree" concepts[23] for a variety of uses became admirably suited to the purpose of energy production and recently have been incorporated into forestry energy studies in many countries.[25]

Grantham[10] noted that intensive short-rotation management of forest plantations offer several advantages: (a) higher yields per hectare with smaller land requirements, (b) earlier return on investment, (c) increased labour efficiency through mechanization, (d) reduced planting costs due to resprouting, and (e) opportunity to take quick advantage of cultural and genetic advances. Among the potential disadvantages are: (a) high initial establishment costs, (b) sites should be suited to mechanized operations, and (c) monoculture may be susceptible to epidemic disease and insect infestation.

Energy plantations are comprised of genetically improved, intensively cultivated, often closely-spaced trees which can be harvested repeatedly (after resprouting) on cycles of 10 years or less. Broadleaved genera such as *Eucalyptus, Leucaena, Alnus, Platanus, Populus* or *Salix* are usually chosen for this purpose.[2] In Ontario, considerable effort has been expended over the past dozen years in developing this concept for poplar (*Populus*) and more recently with willow (*Salix*).

Why do we concentrate on poplar? They have great ecological amplitude and grow on a wide variety of soils and climatic conditions in Canada. Studies of natural variation, breeding experiments and estimates of heritability indicate great potential for the improvement of growth, form, and a number of wood properties in poplars. A rapid genetic gain can be obtained by selection and breeding followed by clonal propagation.

When properly selected, such hybrid poplars have fast vigorous growth, have a uniform predictable quality, can be vegetatively propagated, will respond favourably to intensive culture and have the facility to regenerate by coppicing or stump sprouting.

Related poplar species, when crossed or hybridized, often produce offspring with hybrid vigour or "heterosis". Frequently such offspring arise from parental combinations originating in geographically isolated regions, such as the cross between *Populus nigra*, the black poplar of Europe, and *P. deltoides*, the North American cottonwood. The tree-improvement process begins with the selection of high quality male and female parents. Branches bearing flower buds are collected and forced into flower in the greenhouse. Female flowers are pollinated under strict control with pollen collected from specified male parents and the seeds mature in 4 to 6 weeks.

Seedlings produced from this seed are outplanted in progeny trials and scrutinized for the best individual performance. These select trees are then vegetatively reproduced by means of stem cuttings to produce clones. A clone, therefore, is a collection of identical plants reproduced from a single original tree by such stem cuttings. Clones are outplanted in trials from which the superior ones are then selected for mass propagation and pilot-scale management trials.

Hybrid poplar is being researched for a variety of potential uses in addition to energy and many forms of management are considered. Poplar plantations can be established at wide spacings of 5 to 10 m and grown 15 to 30 years to produce log-sized trees suitable for veneer. When planted somewhat closer (3 to 4 m), boltwood trees are produced suitable for pulping at 10 years. Minirotations are closely spaced and managed on 1 to 3 year rotation much like an agricultural crop to produce a variety of products ranging from animal food and chemical feedstock to particle board furnish. However, the success of all systems depend on common prerequisites of selecting adequate soils, clone/site matching, weed control, choice and maintenance of proper spacing, and control of pests.[24] In most instances, yields may be further improved through the application of fertilizer and irrigation schedules.

The biomass yields of hybrid poplar plantations are impressive. Table 1 illustrates some typical productivities of a range of ages and types of management. Yields of approximately 10 $odt.ha^{-1}.a^{-1}$ are commonly achieved with variations attributable to site, clone type and intensity of management. The plant material produced in such plantations has been analyzed for many potential uses.[6] In addition to the direct combustion value of such material, other energy related products studied have been alcohols and lignin,[22] wood oils,[4] and animal feeds.[7]

Genetic Improvement of Energy Plantations

Since clones are genetic replicas of superior or elite trees, cloning can capitalize on the population and family variation in desired biomass characteristics.[1] Clonal selection can stabilize these characteristics at an optimum level. Not only yield, but biomass quality is predictable and homogeneous.

There is some evidence that genetics may play a role in controlling to some extent the energy content of trees. Sastry and Anderson[18] found that significant clonal variation occurred in the mass energy density among 10 clones of 2-year-old hybrid poplar (Table 2). This suggested that poplars could be selected and perhaps bred for higher-than-average heating value.

As a result of this and other studies, the Ontario Ministry of Energy, in further support of its targeted role for energy forests in Ontario, funded in 1981 a hybrid poplar energy survey to be carried out at the Ontario Tree Improvement and Forest Biomass Institute, at Maple. This two-year study, now approaching completion, proposed to screen 133 clones of 1-year hybrid poplar coppices (Fig. 1) and to select high performance clones for further development. The study also attempts to partition variation in gross heat of combustion among genetic (e.g. parental lineage) factors and chemical and physical characteristics of the clones (e.g. extractive content, specific gravity etc.). Ideal clonal candidates for selection would be those combining high biomass productivity with high energy contents coupled with other desirable traits (i.e. good rooting, pest resistance, etc.).

Fig. 2 shows the frequency distribution of the 133 clones according to their oven-dry biomass productivity. While the average productivity is 7.3 odt.ha^{-1}.a^{-1}, clones DN182 and N75 are more than 3 standard deviations above that value and produce biomass at the rate of 20 odt.ha^{-1}.a^{-1}. These clones, along with DN87 at 15 odt.ha^{-1}.a^{-1} are attractive candidates for selection using productivity criteria.

Fig. 3 illustrates the distribution of 30 of these clones in terms of gross energy of combustion. The average energy value is 19780 joules.g^{-1} and it can be seen that clone MAX2 is 2 standard deviations greater than this average and thus considered to be of superior energy value. The range in energy density shown by these initial 30 clones is of the order of 5%, and less than the 15% expected on the basis of earlier work. However, the maximum values found to date are higher than those values normally ascribed to poplar wood and yet higher values will be expected over the course of the additional 100 clones being tested. It is of interest to note that the high biomass producers (DN182 and N75) fall in the lowest and median zones of the energy distribution.

A more useful ranking of clones, however, is on the basis of energy production per hectare. By combining productivity values (g.ha^{-1}) with energy value (j.g^{-1}), the energy productivity (Gj.ha^{-1}.a^{-1}) can be computed. Fig. 4 shows such a distribution for 30 clones. It can be seen that the average value is 177.6 Gj.ha^{-1}.a^{-1} and that clone N75 is greater than 2 standard deviations larger while MAX2 is in the lower quartile. This reflects the fact that biomass variation contributes more strongly to energy productivity than does energy value itself.

While final selections will obviously await completion of the study, two time-frames of action can be foreseen. Firstly, the clones which at the time show greatest energy production can be selected and propagated for immediate use in energy plantations. Secondly, further hybridization between high biomass producers (e.g. N75) and high energy clones (e.g. MAX2) will be attempted to combine the genes for these two attributes into single offspring.

Specific gravity seems poorly correlated with energy content with the exception of those in which extractive content contributes to higher density. Fig. 5 illustrates the clonal variation in specific gravity for 30 clones. The mean value is 0.295 and the range extends from 0.24 to 0.38. Four of the five highest density clones are balsam poplars characterized by high extractive content. Previous work with willows has suggested that both kind and quantity of extractives may contribute to energy content of clones. Thus a third plan of action to produce clones of exceptional energy content would involve studies of growth processes and environmental factors influencing extractive formation. Since many extractives are "secondary metabolities", accumulating rather like waste products, their rate of formation may be modified through cultural manipulation of the growing conditions.

Some Limiting Factors

In the energy plantation concept, the energy input required to achieve high yields is of crucial importance. There must be a substantial net energy gain when input (energy spent in production and harvesting) is compared with output (biomass energy produced). Net energy efficiency ratios (input:output) for energy plantations have been found to vary from 1:10 to 1:15.[13] Inman and Salo[14] conclude that production of silvicultural biomass in short rotation systems is not energy intensive and would not be precluded because of an unfavourable energy budget.

Irrigation and fertilization practices may lower efficiency ratios;[17] however the use of effluents and waste water may provide both irrigation and partial fertilization at marginal cost. Return of combustion ash to plantation sites may also be a means of lower-cost amelioration. However, clonal selection can also play a role in controlling nutrient drain from harvested sites. As seen in Fig. 6, clones can be selected which combine high biomass productivity with lower-than-average nutrient content i.e. those clones which are efficient users of soil nutrients.

Most biomass energy sources suffer from a condition of high moisture content. In fact, energy efficiency ratios are quite sensitive to the expenditure of energy to "dewater" wood. Plant tissue may be partially seasoned by transpirational drying in which the trees are cut with leaves intact and left to dry out "in situ". In such cases, however, clones tolerant of harvesting during the non-dormant season must be carefully selected to avoid damaging sprouting ability.

Low bulk density is another characteristic of biomass fuels. While high density clones may be selected perhaps it is most efficient to select clones on the basis of "volume energy density" rather than "mass energy density" as discussed previously. Densification and pelleting processes largely alleviate transportation and storage problems of low density and they also tend to lower moisture content, but at added cost. On the other hand, our studies have suggested that particle size affects the energy values associated with hybrid poplar as well, such that heating values increase somewhat as particle size decreases. This suggests that product form may also be a major consideration, and recent developments in Sweden have made use of wood in its pulverized or flour-form as an energy source.[3]

Production costs are greatly affected by yield, but become less sensitive as productivity increases above 15 odt.ha^{-1}.a^{-1}.[9] Planting costs are a major concern with densely-spaced minirotations; however, techniques of broadcast or scatter planting, in which cuttings are loosely placed horizontally and subsequently covered with soil, show considerable promise in reducing such costs. Harvesting of smaller material also tends to be costly, mainly because of handling beds and corridors and grown in 1- or 2-year rotation could be considered a type of "silage forest" harvested by units similar to corn-binders which would combine harvesting and on-site chipping.

Availability of land suitable for intensive management will be a major concern in the near future. In fact, because of its versatility, poplar biomass may tend to compete for various products. However, hybrid poplars may be less suitable for other products such as food when bred specifically for energy because of higher lignin content. To satisfy markets in northern Ontario, where land may be more easily available, clonal selections with improved frost hardiness and site tolerance will be required.

Future Prospects

The feasibility of producing large amounts of biomass of defined quality on short time-scales has been adequately demonstrated for the various management systems on a variety of sites. The cost-effectiveness and product competitiveness will require constant improvement, especially for the more radical approaches such as minirotation.

Technique modifications in such areas as harvester design, transport systems, and planting methods will undoubtedly increase the production efficiency of hybrid poplar biomass. Important genetic gains can be foreseen with the development of advanced breeding techniques of tissue culture and protoplast fusion which will reduce the time required to produce new genetic combinations.[5,12] Certainly such a remarkable renewable resource will have a significant role to play in Ontario's energy future.

Literature Cited

1 Anderson, H.W. and L. Zsuffa. 1982. Genetically improved forest biomass energy production. Proc., Fourth Bioenergy R & D Seminar, Winnipeg, Manitoba. pp. 392-394.

2 Anderson, H.W., C.S. Papadopol and L. Zsuffa. 1983. Wood energy plantations in temperate climates. Jour. Forest Ecology and Management. (In press.)

3 Anonymous. 1982. Powdered wood fuel invented in Sweden. Wood'n Energy 2 (11): 8.

4 Boocock, D.G.B. and D. MacKay. 1980. The production of liquid hydrocarbons by wood hydrogenation. Proc. IGT Symp. "Energy from biomass and wastes IV", Florida. 13 pp.

5 Brown, C.L. 1976. Forests as energy sources in the year 2000: What man can imagine, man can do. Jour. Forestry 74 (1): 7-12.

6 Canadian Forestry Service. 1980. Canada's forests. Pamphlet. 9 pp.

7 Chen, C.P., D.N. Roy and H.W. Anderson. 1979. Hybrid poplar leaves as a source of protein and other useful products. *In* D. Fayle, H.W. Anderson, L. Zsuffa (eds.). Poplar research, management and utilization in Canada. Ont. Min. Natural Resources, For. Res. Inf. Paper 102. 11 pp.

8 Fayle, D.C.F., H.W. Anderson and L. Zsuffa (eds.). 1979. Poplar research, management and utilization in Canada. Ontario Ministry of Natural Resources, Forest Research Inf. Paper 102.

9 Fege, A.S., R.E. Inman and D.J. Salo. 1979. Energy farms for the future. Jour. Forestry 77: 358-361.

10 Grantham, J.B. 1977. Anticipated competition for available wood fuels in the United States. *In*: D.A. Tillman ***et al.***, Fuels and Energy from Renewable Resources, Academic Press. pp. 55-91.

11 Hall, D.O. 1980. Biomass: Solar energy through biology-fuels now and in the future. *In* Troisièmes Assises Internationales de l'Environnement, Paris, France. pp. 411-444.

12 Ho, R. 1982. The state of the art and potential of biotechnology in forest tree improvement. Proc. 9th Mtg. of International Energy Agency, Ghent, Belgium.

13 Inman, R.E. 1977. Silvicultural biomass farms. Vol. I Summary. Mitre Corp., Metrek Div., Tech. Report 7347, 62 pp.

14 Inman, R.E. and P.S. Salo. 1977. Silvicultural biomass farms. Proc. Fuels from Biomass Symp., Univ. Illinois, Urbanu, Ill., pp. 29-36.

15 McAlpine, R.G., C.L. Brown, A.M. Herrick and H.E. Ruark. 1966. Silage sycamore. Forest Farmer 26: 6-7, 16.

16 Province of Ontario. 1980. Energy from waste – a program for Ontario. Ontario Ministry of Energy, 27 pp. (unnumbered).

17 Rose, D.W., K. Ferguson, D.C. Lothner and J. Zavitkovski. 1981. An economic and energy analysis of poplar intensive cultures in the Lake States. USDA For. Serv., Res. Paper NC-196, 44 pp.

18 Sastry, C.B.R. and H.W. Anderson. 1980. Clonal variation in gross heat of combustion of juvenile ***Populus*** hybrids. Can. Jour. Forest Research 10 (3): 245-249.

19 Saul, V. and W.E. Knowland. 1980. Energy in the developing world: the real energy crisis. Oxford Univ. Press, Oxford, 300 pp.

20 Schreiner, E.J. 1970. Minirotation forestry. USDA, For. Serv., Res. Paper NE-174.

21 Szego, G.E. and C.C. Kemp. 1973. Energy forests and fuel plantations. ChemTech, May 1973. pp. 275-284.

22 Wayman, M. 1977. Ethanol for motor fuel from biomass. Proc. Forest and Fuels Symp., Biomass Energy Institute, Winnipeg, Manitoba, 13 pp.

23 Young, H.E. 1964. The complete tree concept – a challenge and an opportunity. Proc. Soc. Amer. Foresters Ann. Mtg., pp. 231-233.

24 Zsuffa, L., H.W. Anderson and P. Jaciw. 1977. Trends and prospects in Ontario's poplar plantation management. Forestry Chronicle 53: 195-200.

25 Zsuffa, L. 1981. The production of wood for energy. Proc. XVII IUFRO World Congress, Japan, Div. 3: 404-413.

Typical Performance Data for Hybrid Poplar Plantations Growing in Ontario

Table 1

Clone	Age (yrs)	Height (m)	DBH (cm)	Volume ($m^3.ha^{-1}$)	Biomass (odt.ha.$^{-1}$)
P. canescens (cl. C147)	1	3.1	1.2	—	10.2 (coppice)
P. x euramericana (cl. DN25)	2	5.4	3.3	—	33.6 (coppice)
P. x euramericana (cl. I214)	11	15.5	17.5	242.6	84.9 (estimate)*
P. grandidentata x alba (pop. 175)	19	22.7	20.3	506.3	117.2 (estimate)*

*Merchantable volume converted to biomass using nominal specific gravity of 0.35.

Variation in Gross Heat of Combustion Among Ten 2-year-old Hybrid Poplar Clones

Table 2

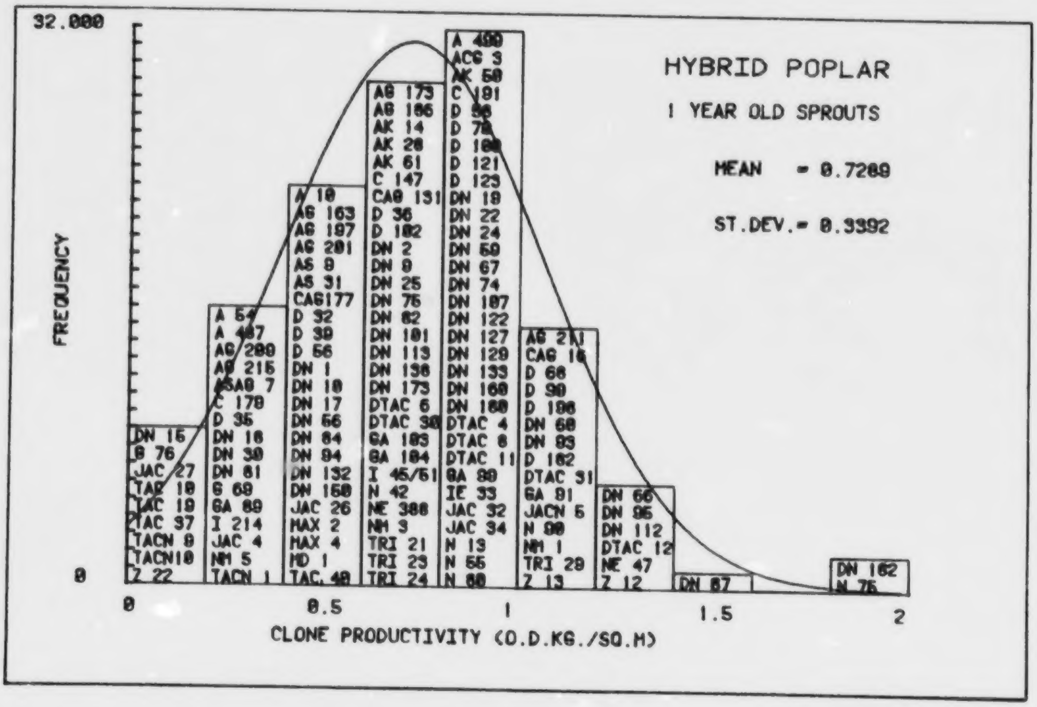
Clone	Calories per gram
D-72	4955 a
DTAC-1	4810 a b
DN-87	4788 b c
I-45/51	4782 b c d
DN-10	4671 b c d
AGC-11	4654 b c d e
GA-88	4639 c d e
A-499	4581 e f
CAG-131	4442 f
AK-14	4357 g

*Clones sharing common letter do not differ significantly at the 95% confidence limit.

One-year-old sprouts of hybrid poplar growing in a closely-spaced coppice system. **figure 1**

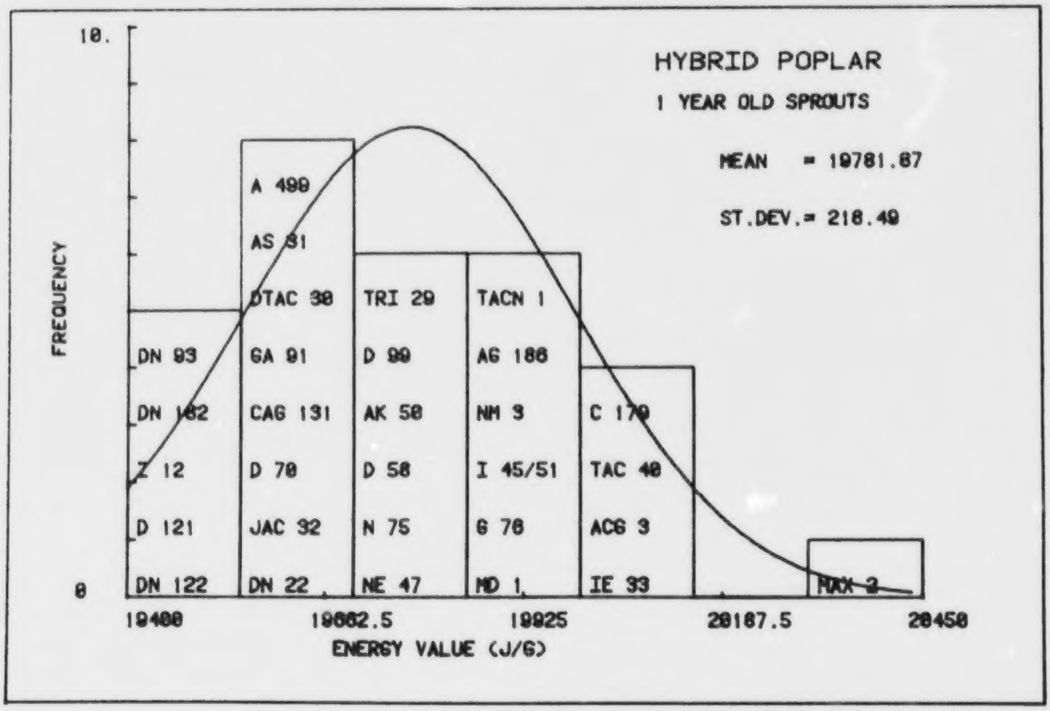
Distribution of biomass productivity among 133 clones of 1-year-old hybrid poplar coppice.

figure 2



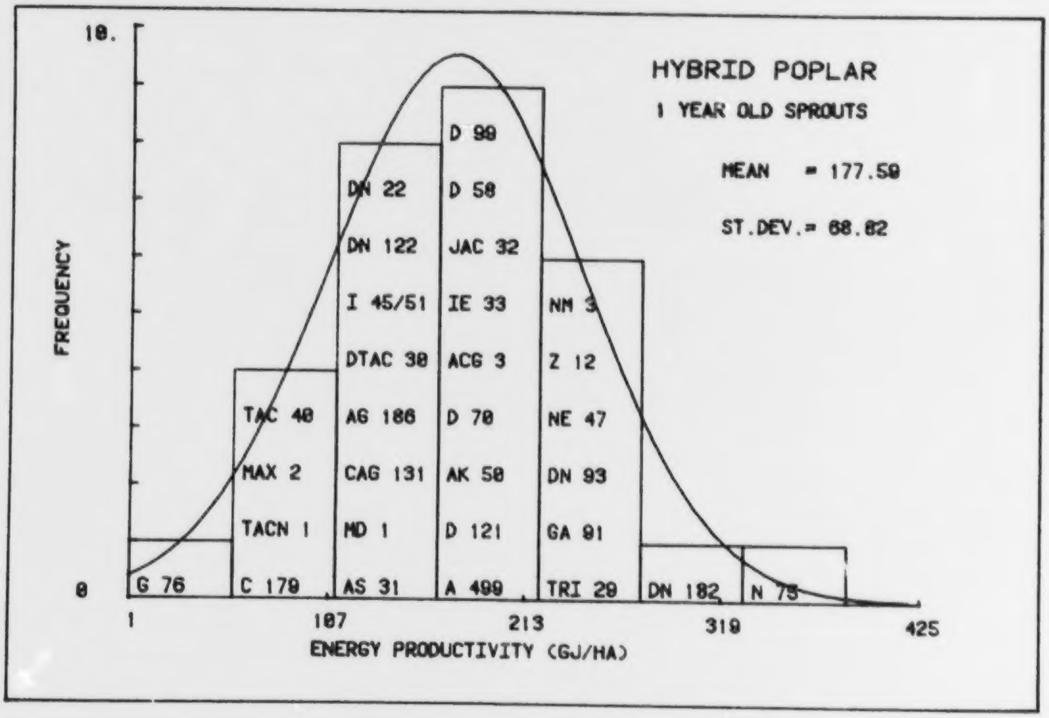
Distribution of mean energy values (gross heat of combustion) among 30 clones of 1-year-old hybrid poplar coppice.

figure 3



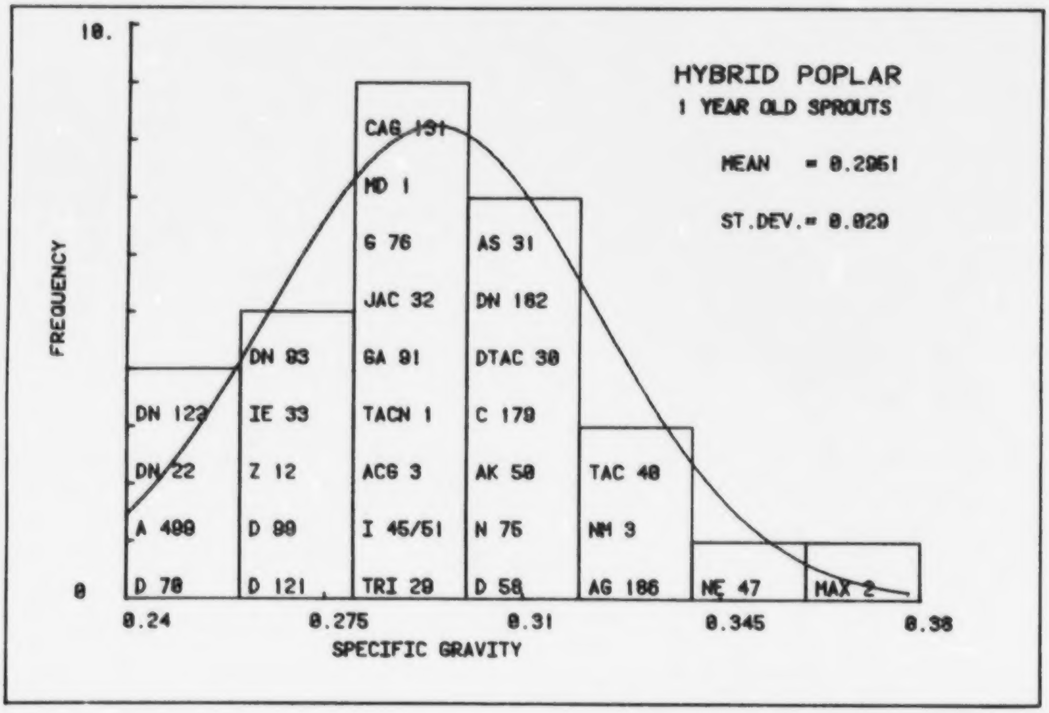
Distribution of mean energy productivities among 30 clones of 1-year-old hybrid poplar coppice.

figure 4



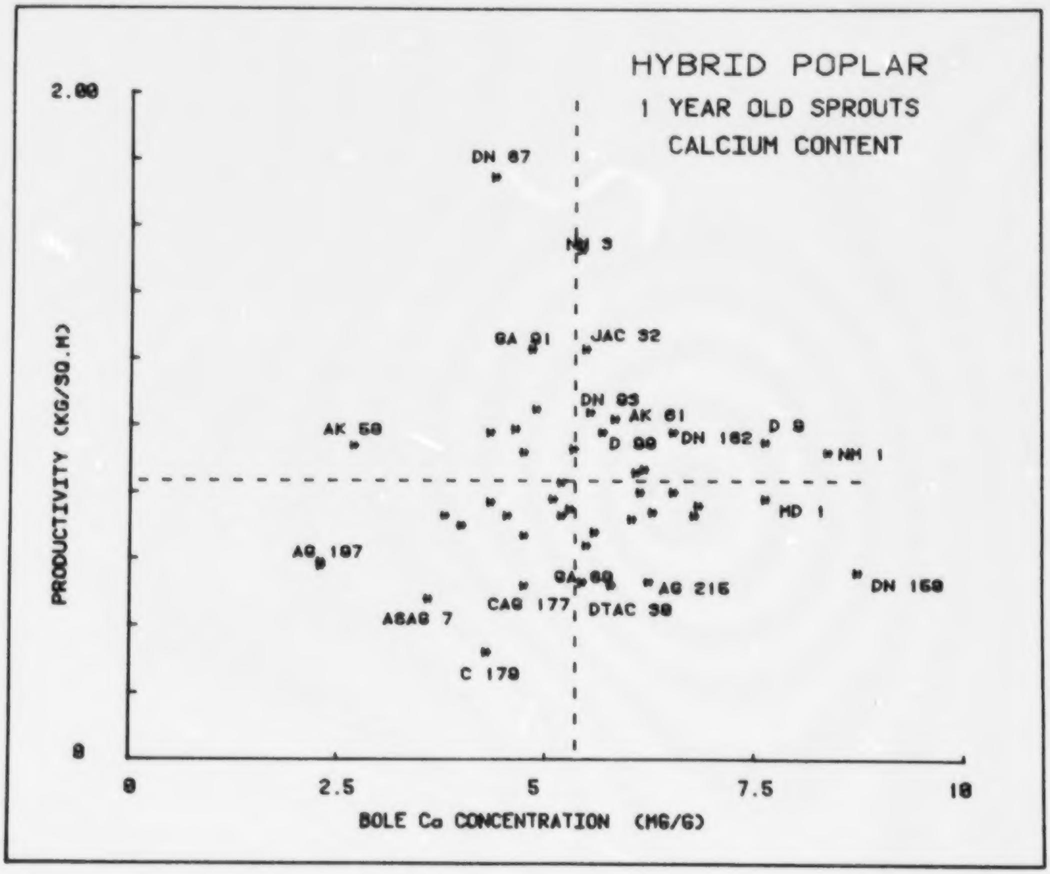
Distribution of mean specific gravity values among 30 clones of 1-year-old hybrid poplar coppice.

figure 5



Relationship between biomass productivity and calcium concentration of stem tissue among 30 clones of 2-year-old hybrid poplar coppice.

figure 6



Pellet Fuel From Wastes

by:
A. S. Borowski
Shell Canada Ltd.

Abstract

Biomass represents an important and widely available source of renewable, alternative energy. Sawmill wastes, in particular, are an attractive source of energy because of availability and price.

In most cases, raw biomass must be converted to a higher grade fuel before burning to reduce moisture and increase its energy density.

Although numerous conversion processes are being developed, most do not appear attractive because of high cost and low energy efficiency.

The patented Woodex® process, for which Shell Canada Ltd. and its subsidiaries, have procured licenses in Canada and other countries, has been demonstrated as commercially successful.

The process consists of size reduction, drying and densifying, to produce small diameter pellets which are an excellent fuel.

Woodex® has a heating value equivalent to two-thirds that of bituminous coal, and higher than most lignite coals. The sulphur content is essentially nil and its physical characteristics make it transportable and easy to handle.

The primary market to date has been industrial, but this is now being extended to include institutional, commercial and domestic.

Shell Canada operates this business through BioShell Inc., a wholly owned subsidiary. Two 360 tonne/day plants are in operation and a third is in the start-up phase.

Ladies and Gentlemen:

My topic today is "Pellet Fuel From Wastes".

Specifically, I intend to present Shell Canada's activities in biomass fuel, and then show some slides taken at one of our plants as well as at one of our customer's locations. I will then attempt to answer any questions you may have.

I am frequently asked how an oil company such as Shell became interested in biomass fuels. The answer is simple; we are not just an oil company but a fully integrated energy company. Alternative fuels development is an integral part of our corporate strategies.

Background

We first started looking into biomass fuels late in 1977. Naturally we were exploring for opportunities created by the rapidly increasing fossil fuel prices.

Our first problem was where to start? We were very green and somewhat bewildered by the vast array of options available, ready to double our profits and spell doom to the oil side of our business.

Common sense prevailed however, and we soon realized that biomass fuels were at the economic threshhold. The route to riches would be longer and far more painful than some protagonists would have us believe.

A list of criteria was established to identify options suitable for immediate development. If you will forgive the pun – we attempted to observe the forest in spite of the trees.

Slide 1 illustrates the approach taken. Once the criteria were established, it was a relatively easy task to select the biomass resource, the conversion process and the prime market. Indeed our entry into biomass fuels follows this strategy; we buy mill wastes, manufacture an excellent solid fuel and sell primarily to the industrial market.

The Resource Base

I do not wish to dwell long on forest resource availability, as I am sure the subject was covered extensively by earlier speakers. I would, however, like to make a couple of points as follows; (See Slide 2).

The resource base is very large amounting to some 53 million oven dry tonnes per year. This is equivalent to 158 million barrels of No. 6 fuel oil, which in turn equates to the energy output of 3 tar sands plants.

In most instances, the delivered cost of forest biomass, other than mill residues, is too high for fuel use. However, on the assumption that domestic fossil fuel prices will continue to increase in real terms, and improved methods of recovering logging residues are developed, it is just a matter of time before we see extensive utilization of those residues for fuel use.

The Pelletization Process

There are numerous processes available for the conversion of wood to energy and chemicals; however, all of them with the exception of direct combustion, are in the development stages. Products such as methanol, ammonia, SNG, synthetic fuel oil manufactured from wood, cannot compete with current Natural Gas or fuel oil prices.

Some time ago, the "Advisory Group on Synthetic Liquid Fuels in Ontario", a study which I believe was sponsored by the MOE, concluded that, quote: "In terms of capital investment and energy use efficiency, it is preferrable to burn wood or municipal solid waste as solid fuels, in order to displace distillate or fuel oil for upgrading to transportation fuels", unquote.

We subscribe to the above statement which fits in with our strategy we have discussed earlier.

The pulp and paper industry have been burning hog fuel for many years, recovering useful energy and solving a waste disposal problem at the same time. The sawmill industry on the other hand, in most cases, has continued disposing its wastes by incineration and landfill. Their thermal energy needs are only a fraction of the energy contained in the bark and sawdust residues. Not surprisingly, they found it difficult to justify spending capital on a project resulting in a relatively minor recovery of energy and leaving them with the disposal problem. The challenge and opportunity appeared to revolve around a better utilization of sawmill wastes.

Late in 1977, we came across the patented Woodex (R) pelletization process. This process seemed to suit the need indentified previously, and in 1978 we procured a license for Ontario and Quebec.

The concepts involved in biomass pelletization are simple. They consist of size reduction, drying and densifying. It is the practical application of these concepts to a commercial size operation that presents a challenge.

A simplified flowscheme is shown on Slide 3. Mill wastes consisting of bark, sawdust, tops, butts, etc., are delivered by tractor trailers, dumped and stockpiled at the plant. Front-end loaders retrieve the wastes from the stockpile into the feed conveyor system. All metallic contaminants are removed prior to hogging. Following size reduction in the hog, the wastes, containing approximately 50 percent moisture, are fed into a rotary kiln dryer. The drying medium is hot air and gases generated by burning pulverized pellet fines in suspension. The moisture-laden flue gases are cleaned using cyclone separators and vented to atmosphere. The moisture content of the wood at the outlet of the dryer is carefully controlled to a selected level, depending on a number of factors such as wood species and composition. The dry material is hammer milled and routed to the densification section.

The pellets are formed by compressing the feed between a rotating die and rollers, and then extruding through holes in the die. The application of high pressures, temperature and careful feed conditioning combine to produce high quality fuel pellets. The pellets are cooled and screened to remove fines and then routed to storage. The fines are recycled and used as fuel for the dryer.

Slide 4 is a schematic representation of what occurs within a pellet mill.

Approximately two tonnes of wet, raw material are required to produce one tonne of pellets. Own consumption fuel amounts to roughly 15 percent of the feedstock. Shell Canada's first wood pelletization plant was built in Hearst, Ontario. The plant was brought onstream in early 1981. It took approximately six months to bring it up to its rated capacity of 330 tonnes/day, and since then output has increased to 360 tonnes/day.

The Product

The properties of Woodex® pellets are summarized on Slide 5.

The heating value is approximately two-thirds that of bituminous coal and higher than most lignite coals.

Moisture is low, typically 6 percent. Therefore, the fuel does not freeze in the winter.

The ash content is low compared to most coals.

The sulphur content is essentially zero, which makes pellets a particularly attractive fuel where acid rain is recognized as a problem.

Pellets have a high bulk density which results in significant savings in handling and storage.

The cylindrical shape of the pellets and their small size, gives them unique handling properties. They flow easily with no danger of bridging in bins or silos.

A comparison between bituminous coal, wood pellets and hog fuel is shown on Slide 6. The left hand side shows the relative weights of these fuels required per unit output from a boiler. The right hand side shows a similar comparison but on a volumetric basis. It requires two and one-half times the weight and five times the volume of hog fuel, compared to pellets, to produce the same amount of net heat. Naturally these facts have significant effects on the capital and operating costs of transport, storage and handling.

The advantages of wood pellets over hog fuel are summarized on Slide 7.

The Market

A variety of industries and institutions provide a ready market, because Woodex (R) pellets can be used in existing coal-fired boilers and furnaces. In most cases, Woodex (R) can replace coal with little or no conversion cost and without the expense of installing pollution control equipment. Furnaces and boilers designed for oil or gas must be modified to burn Woodex (R). The use of wood pellets is not restricted to industries and institutions. Manufacturers of home heating units have recognized the viability of Woodex (R) in domestic applications. Successful tests have been carried out on modified furnaces and already some units have been installed in homes.

Economics

Most of the product from our first two plants is being used by industry. We are able to offer fuel pellets at a delivered price which is significantly below the price of the cheapest industrial fossil fuel; i.e., interruptible natural gas. Naturally anyone using No. 6 fuel oil will find the pellets very attractive.

Commercial and institutional users can expect prices to be 10 to 25 percent below that of natural gas.

We have set up distributorships to handle the domestic market. We anticipate that pellets will be delivered to homes at no more than 75 percent of the cost of No. 2 fuel oil.

Status and Future Plans

Shell Canada Ltd., has set up a subsidiary company called BioShell Inc., to develop and operate the wood pelletization business.

Two plants are already in operation in Ontario and a third plant is being brought onstream in Quebec.

Our program calls for building a total of ten plants during the next five to six years. These plants will use millwastes as their primary source of feedstock.

Towards the end of this decade we foresee that forest slash and peat may become economical feedstocks.

The economics of pellets, as of any other alternative fuel, are of course primarily dependent on the domestic prices of fossil fuels. How these prices will move over the next ten to fifteen years, nobody knows. One point is clear; that in order for the biomass fuel industry to experience a satisfactory rate of growth, the domestic oil prices must increase in real terms during the next few years.

Biomass Process Selection

Slide 1

Biomass Resource	• Low Price • Concentrated • Plentiful	• MSW • Agri Wastes • ***Mill Wastes*** • Harvest Residues
Conversion Process/Product	• Low Cost • Low Conversion Loss • Technology Available	• ***Solid Fuels*** • Gaseous Fuels • Liquid Fuels
Market	• Large • Concentrated • Year-round Demand	• Domestic • Commercial/Institutional • ***Industrial***

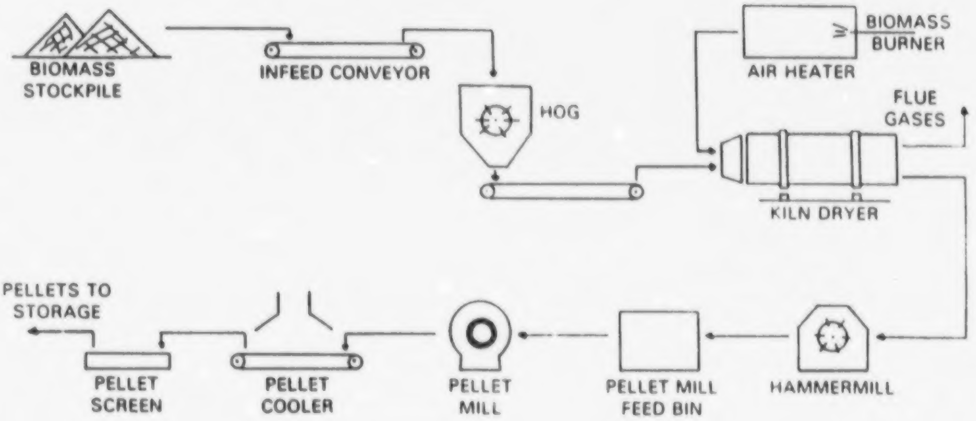
Energy Available from Forest Biomass in Canada

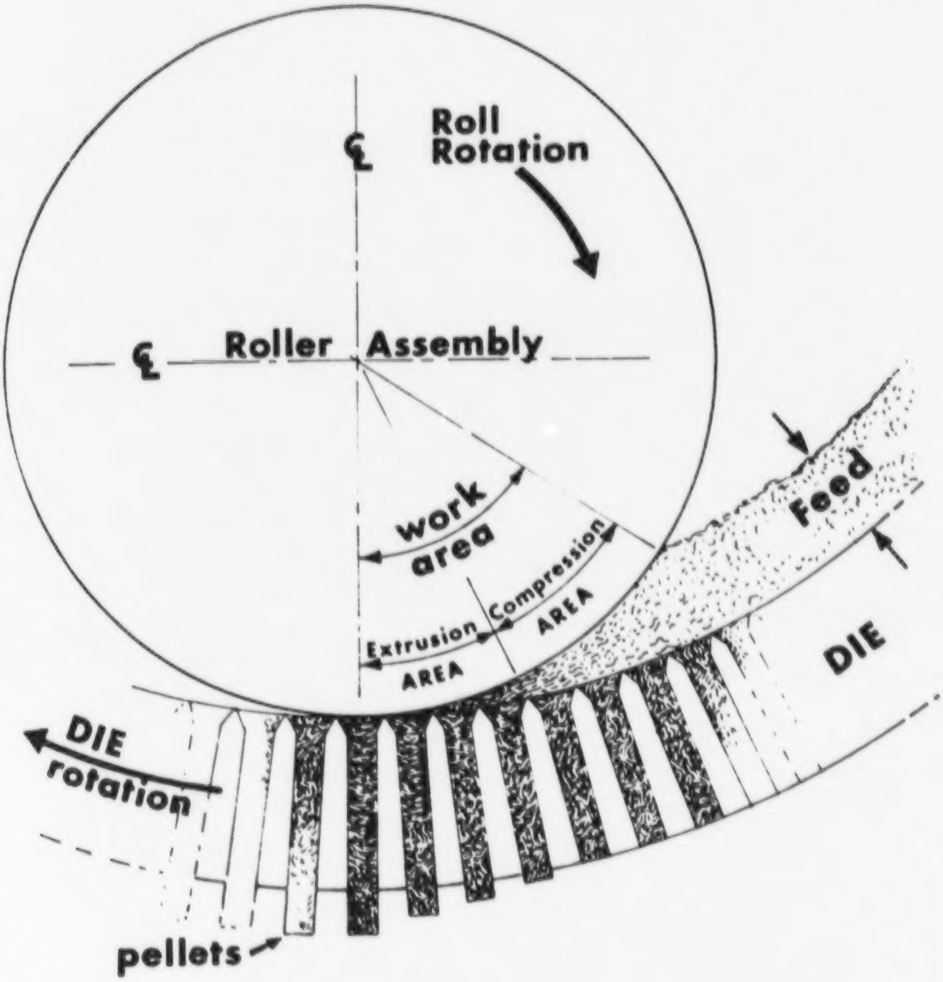
Slide 2

	Net Availability (OD) Tonnes/Yr x 10^6	**Price Range** $/OD Tonne	**No. 6 Fuel Oil Equivalent** Barrels/Yr x 10^6
Mill Residues (Surplus to Current Use)	6.8	0 – 10	20.3
Logging Residues Left in Forests	28.1	40 – 75	83.7
Unutilized Trees in Currently Logged Areas (Too Small, Wrong Species, Etc.)	18.1	45 – 55	54.0
TOTAL	53.0		158.0

Woodex® Pellet Production Flowscheme

Slide 3




Roll
Rotation
℄
℄ Roller Assembly
work
area
Compression
AREA
Extrusion
AREA
Feed
DIE
DIE
rotation
pellets

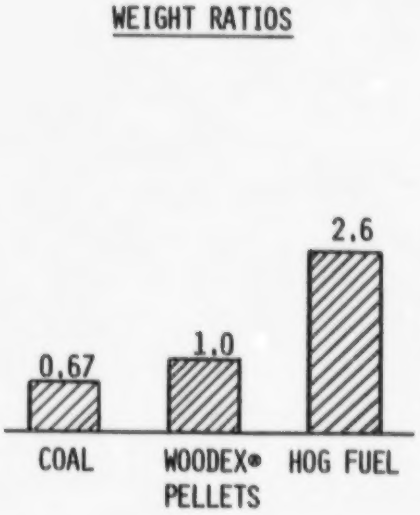
Typical Woodex® Properties

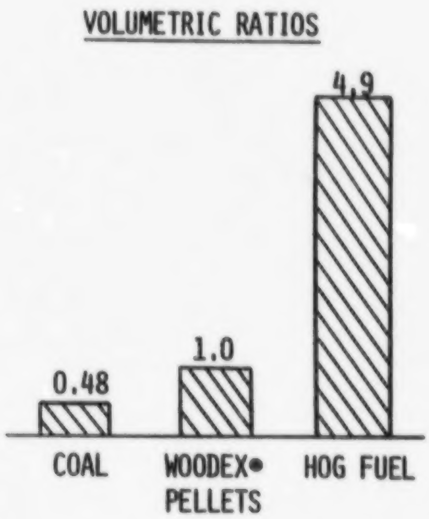
Slide 5

Higher Heating Value:	19 MJ/kg (8,200 BTU/lb)
Moisture Content:	6% wt
Ash Content:	1 – 3% wt
Sulphur Content:	0.1% wt
Bulk Density:	640 kg/m³ (40 lbs/ft³)
Dimensions (Ins):	6.4 mm Diameter x 19 mm Long (0.25" Diameter x 0.75" Long)

Fuel Comparisons Based on Boiler Outputs

Slide 6





Advantages of Dried & Pelletized Fuel vs Hog Fuel

Slide 7

- Increased **Boiler Capacity** in an Existing Boiler
- Lower **Capital Costs** for a New Boiler Installation
- Lower **Particulate** Emissions
- Reduced **Transportation Costs**
- Reduced **Handling Costs** (Storage, Conveying)
- Higher Thermal **Efficiency**
- Specification Product; **Uniform Quality**
- Can be Fired in **Suspension** or on a **Grate**
- No **Freezing** Problems

The Utilization of Biomass Residuals at the Great Lakes Forest Products Thunder Bay Complex

by:
A. J. Bruley
Energy Co-ordinator

Abstract

A general description of power production at the GLFP Thunder Bay Plant is given with special emphasis on the combustion of biomass residuals. The plant operates two wood waste power boilers, two Kraft Recovery furnaces burning spent organic solids, three pulverized coal firing boilers and one fluidized-bed reactor fueled with contaminated wood residues.

New developments include the installation of a rotary bark drying system, a wood waste pulverized suspension firing system and a vapor recompression evaporator unit that reclaims organic solids as a fuel source.

On a thermal energy basis, the complex is presently 57% self-sufficient with a potential of 65% when all new systems are fully operational.

Introduction

The present Thunder Bay Mill Complex has evolved from what was originally a newsprint mill built in the 1920's. The steam supply was originally from five boilers operating at 450 PSIG. Two turbine generators (No. 1 and 2), designed for 450 PSIG throttle steam, were installed in 1930 and are still service.

In the late 1950's, plant expansion made it necessary to upgrade boiler requirements. Four of the original boilers were replaced by high-pressure units operating nominally at 200,000 PPH and 850 PSIG. The fifth boiler has since been retired.

With the change to higher pressure, Turbine Generator No. 3 was added in 1962. It was designed to supply extraction steam at 450 PSIG to No. 1 and No. 2 Turbines and provide process steam at 140 PSIG. The present configuration of the Main Steam Plant is shown in Figure 1.

All four boilers can be fired by either oil, pulverized coal or gas. No. 3 Power Boiler was converted to bark burning in 1965 and is now totally dedicated to this service.

In 1966, the No. 1 Kraft Mill came on stream. It had its own separate steam plant with a recovery boiler capable of generating 288,000 PPH at 850 PSIG. Because the Kraft Mill produced more steam than it required, a 2,500 ft., 850 PSIG tie-line was constructed to allow steam transfer from the Kraft Mill to the Newsmill. This has since proven to be a very wise decision, providing flexibility and considerable steam savings. In 1972, No. 4 Turbine Generator was installed at the Kraft Mill and greatly reduced the plant's need for purchased power.

The construction of the No. 2 Kraft Mill in 1976 saw the further expansion of the Kraft Mill Boiler House. The new No. 2 Recovery Boiler has a steaming capacity of 432,000 PPH at 850 PSIG. No. 5 Turbine Generator was also added at this time along with No. 6 Waste Power Boiler having a steaming capacity of 550,000 PPH of which 300,000 PPH was to be produced using residues from the Stud Mill (built in 1972), the Waferboard Plant (built in 1975) and the expanded Combined Woodroom. The configuration of the present Kraft Boiler House is given in Figure 2.

At the present time, the Thunder Bay Complex produces 1,250 tons per day of newsprint, 1,400 tons per day of bleached kraft pulp, 136 million board feet of stud lumber and 200 tons per day of waferboard product for the construction industry. An overall view of the Thunder Bay site is presented in Figure 3. The News-Kraft Complex is presently 57% self-sufficient in thermal energy and 41% self-sufficient in electrical power. This has largely been achieved from the burning of biomass residues in the form of spent liquor solids, sawdust, shavings, and bark residues.

Contaminated Waste Disposal

The expansion of the Combined News-Kraft Woodroom and the construction of the Newsmill primary effluent treatment facilities in 1972 resulted in the generation of approximately 125 O.D. tons per day of clarifier sludge and contaminated wood-bark residues. The disposal of this material presented a special problem due to its high moisture (70-75%) and sand-gravel content.

A fluidized-bed reactor appeared to be the logical alternative to trucking the material to a landfill site. A Copeland Fluidized-Bed Reactor was constructed in 1972 and has proved to be a most effective way to dispose of such material. A flow diagram of this system is shown in Figure 4. The reactor is approximately 24 ft. in diameter and generates a heat load of about 80 million BTU per hour.

Direct scrubbing of the flue gases has produced in the past, substantial quantities of hot water for use mainly in thawing and washing the logs in the Woodroom's de-icing decks. In recent years, the availability of cleaner hot water from the Kraft Mill has pre-empted the need for hot water from the reactor. It is now intended to use heat from this reactor to dry bark residues. Further reference to this will be made later in the section of this paper under "New Developments."

Hog Fuel Handling

The implementation of dry debarking in 1976 created the need for rapid transport of bark residues from the Woodroom. The bark residues from the drums are first collected on belt conveyors and fed to hogging machines. This hogged material is then pneumatically conveyed by pipeline to two storage locations in the wood yard.

The bark feed for No. 3 Power Boiler is presently collected in a silo. From here, it is removed and blown pneumatically by pipeline to the Main Steam Plant some 2,000 ft. away for direct firing to the boiler. The bark feed for No. 6 Power Boiler is deposited directly on an asphalt pad in the wood yard. A front-end loader is then employed to supply a vibrating feeder and belt conveyor system which carries the waste directly to No. 6 Power Boiler.

Purchased hog fuel and residues from the Stud Mill and Waferboard Plant are presently delivered by truck to the storage pad for feed to No. 6 Power Boiler.

Energy Consumption

Figure 5 presents a comparative illustration of the various forms of energy consumption at the Thunder Bay site for the year 1981. Both purchased and self-generated energy forms are represented. All data has been converted to a BTU basis for comparison.

The importance of spent kraft pulping liquor as a self-generated energy form is quite clear. This source alone provided more thermal energy than the total amount of natural gas purchased in 1981. (Natural gas was the primary purchased fuel up to 1981 but has since been replaced by coal.) The energy contribution from self-generated bark and wood waste is also seen to be very substantial. Co-generation at the complex has also resulted in electrical power becoming a significant self-generated energy form. In fact, 41.6% of the site's total electrical power demand was self-generated in 1981.

Figure 6 illustrates the progress made in energy self-sufficiency since 1976. The dramatic increase during the 1976-78 period is primarily due to the start-up of No. 6 Waste Power Boiler and the new No. 2 Kraft Mill. This is confirmed in Figure 7 which shows the rise in the utilization of spent pulping liquor solids and self-generated hog fuel over the past several years. At the end of 1981, the percent energy self-sufficiency at the complex was 57.6%.

New Development in Progress

Wood Waste Pulverized Fuel Suspension Firing

The development of a prototype pulverized fuel suspension firing system is currently underway as a joint effort between GLFP and Combustion Engineering. This new system is being developed on the No. 6 Power Boiler.

It involves the separation and removal of fine material from the existing biomass feed. This material is collected in a hopper, from where it is transferred and injected into a recycle stream of hot flue gases. The hot gases transport the biomass material to a hammermill where it is reduced in size, nd then re-entrained for firing into the boiler as a suspension. The major energy saving aspects of this system come from the reduction in gas consumption during the grate-cleaning periods which occur for three hours each day. Further energy savings will result by using this system to handle moderate steam load swings which are usually taken with gas.

Upgrading Wood Waste Residues

At present, a rotary drum hog fuel drying system is being installed. It will utilize the hot flue gases (1800° F.) from our Copeland Fluidized-Bed Reactor. These gases will be diverted to a Rader-Thompson rotary dryer for intimate mixing with hog fuel having an approximate moisture content of 55%.

The system will handle about 35 tons per hour of the wet bark waste. The moisture content of the final product is expected to be in the 30-35% range. This upgraded hog fuel will then be fed

Energy from Sulphite Spent Liquor Recovery

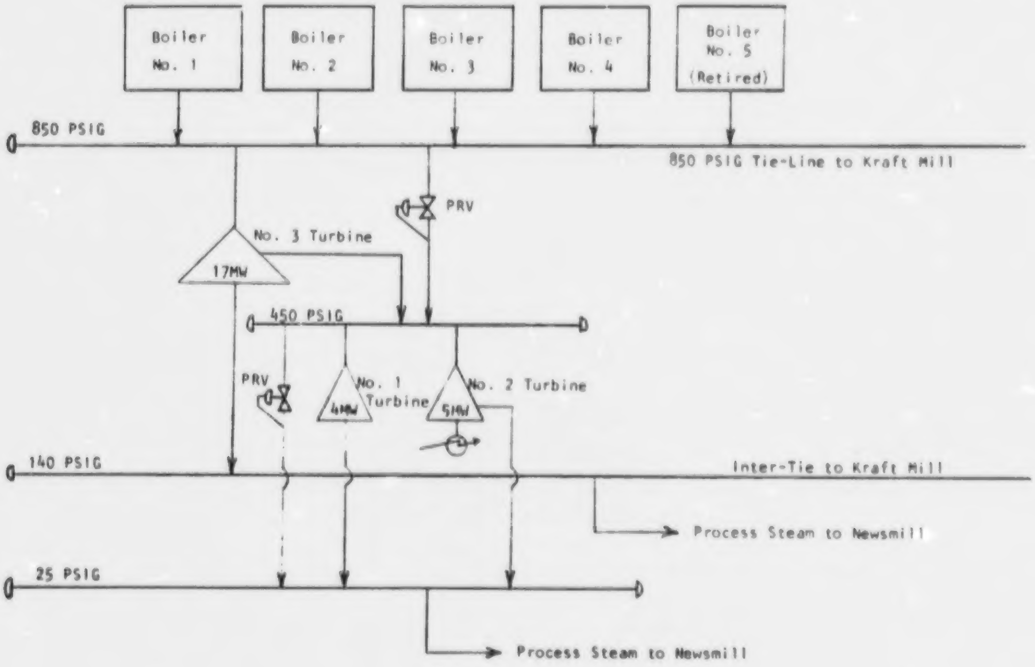
The new sulphite spent liquor recovery system is expected to be on stream by July '83. Although the specific purpose of this system is the elimination of B.O.D. from the spent acid cooking liquors, a considerable energy saving will also result. The spent liquors are to be concentrated to 55% solids using a vapor recompression evaporator and then fired in either of the two Kraft recovery boilers. Energy savings of 350 billion BTU per year are expected to be produced from this waste fuel source, aside from the chemical recovery and environmental benefits.

Conclusions

An overview of the role biomass residuals play in the steam and power production system at GLFP's Thunder Bay site has been presented. It is clear that such residuals have become the dominant energy source. Additional efforts, now underway, will increase the use of these self-generated wastes and further reduce the need for purchased fuels. The complex is expected to become 65% self-sufficient in energy when current projects are fully operational.

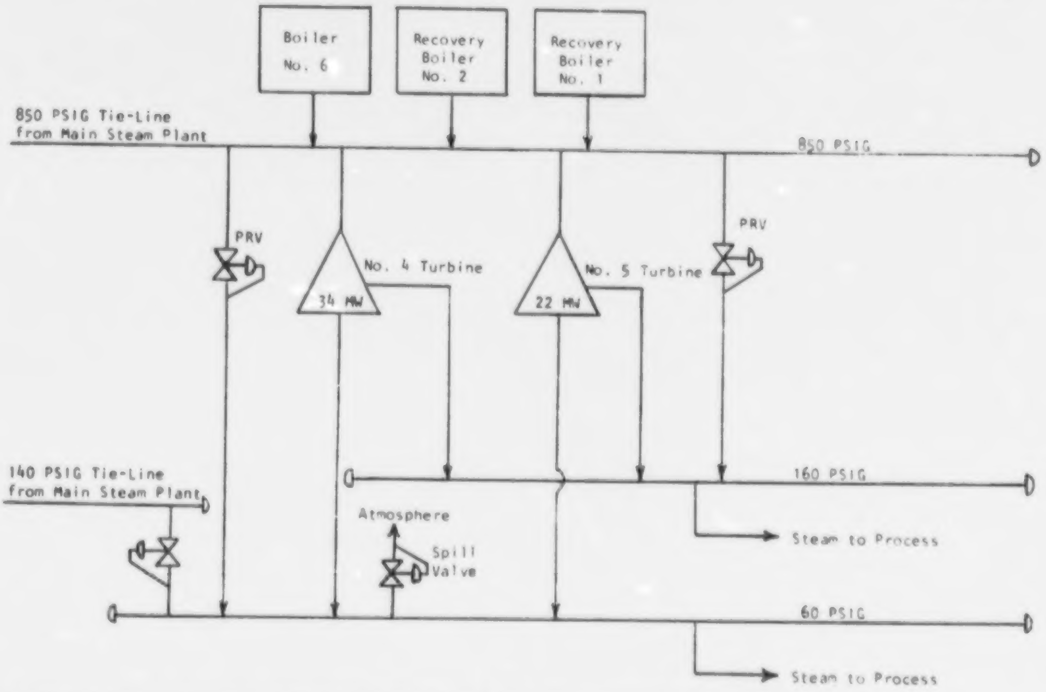
Steam Production and Distribution at Main Steam Plant

figure 1



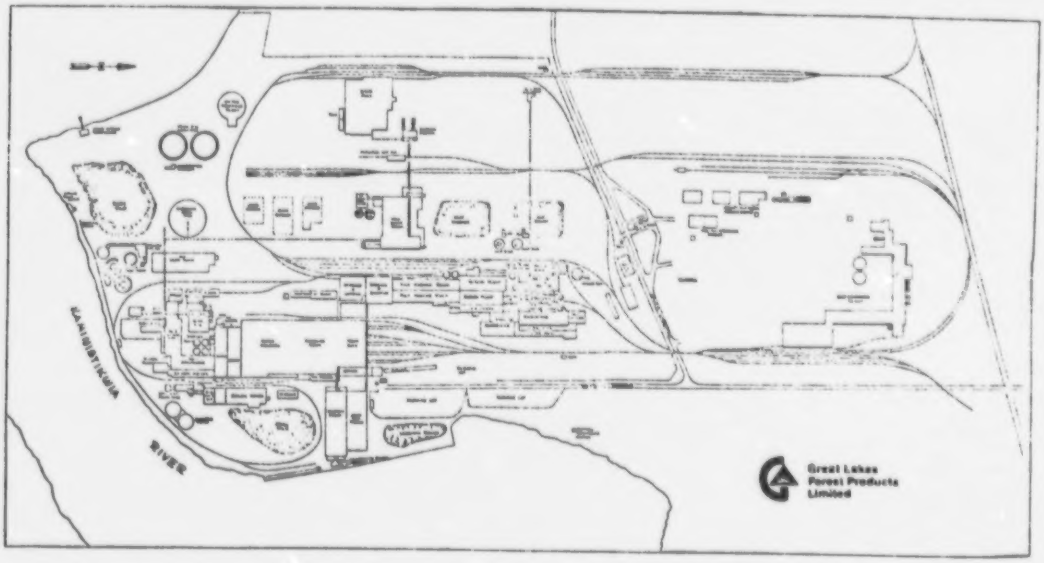
Steam Production and Distribution at Kraft Boiler House

figure 2



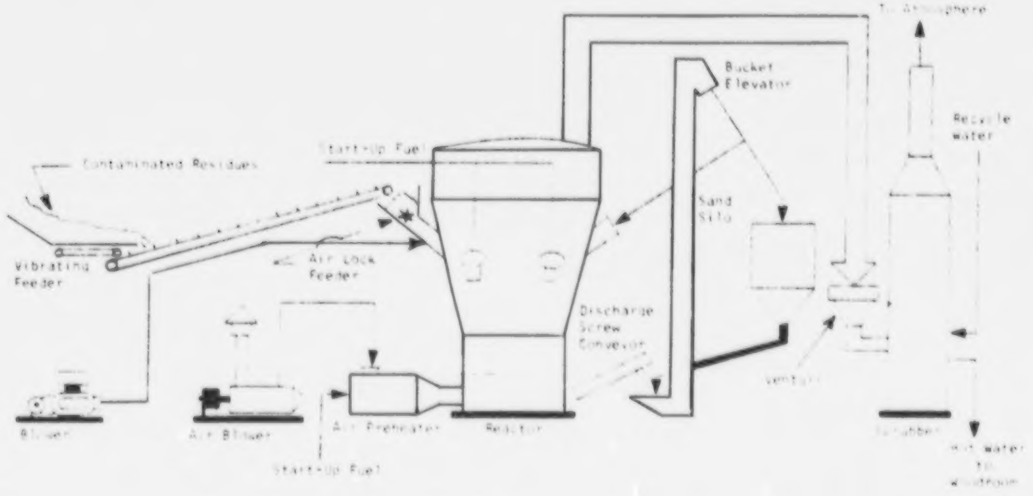
Overview of GLFP – Thunder Bay Complex

figure 3



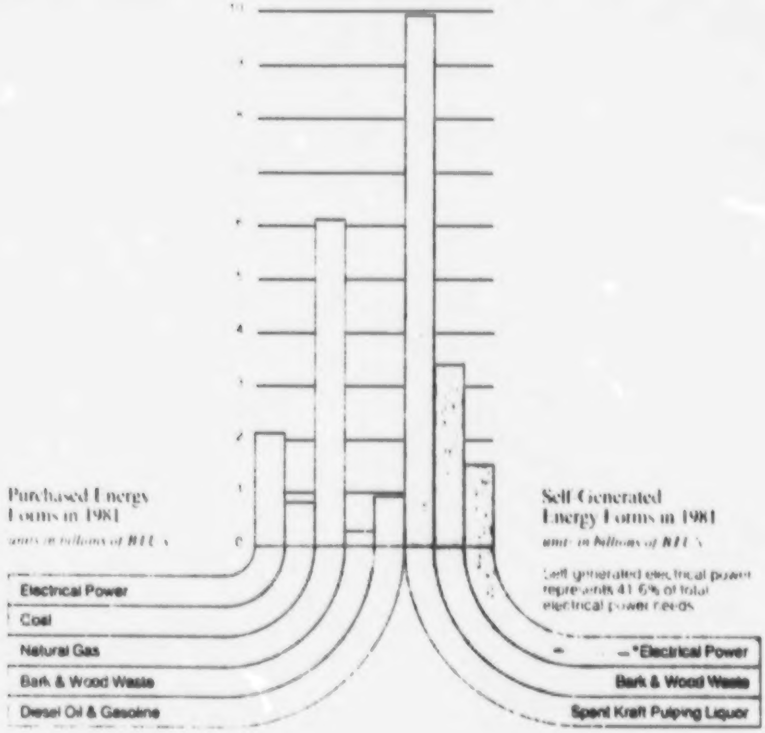
Fluidized-Bed Reactor System for Disposal of Contaminated Bark & Wood Residues

figure 4



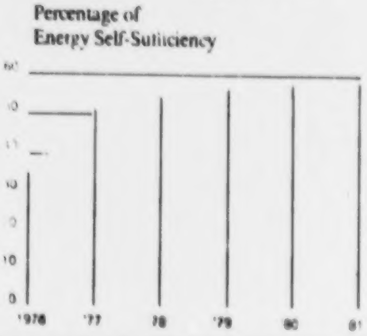
Consumption of Various Energy Forms

figure 5



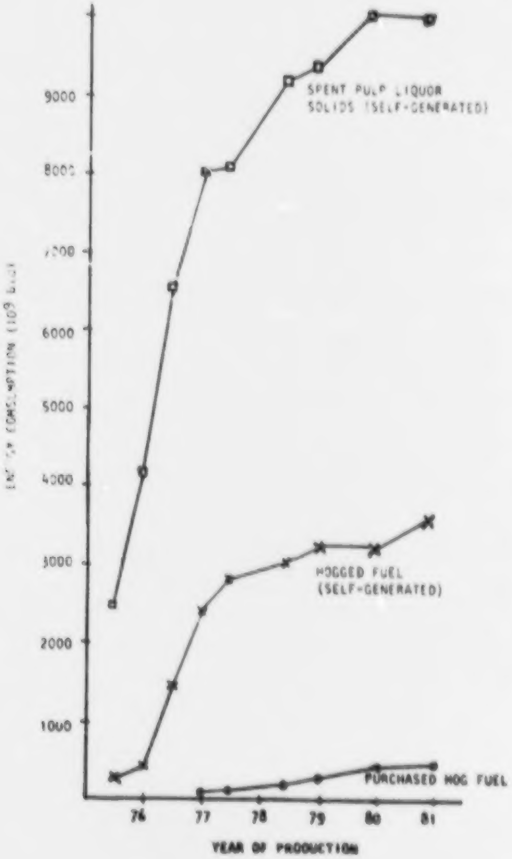
Energy Self-sufficiency Progress

figure 6



Trends in By-product Energy Usage at Great Lakes Forest Products Ltd. — Thunder Bay Plant

figure 7



Woodfired Heating Facility at Grenville Christian College

by:
John P. Childs
and
Daniel E. Ortolani

Abstract

Grenville Christian College is a small, privately owned organization that has actively formulated and pursued a unique energy policy. While many business concerns have simply endured the pain and pressure of rising energy costs, we have been very fortunate to enter into a pilot program in collaboration with the Provincial and Federal Governments, that has allowed us to eliminate the use of oil as our primary energy source. We have replaced oil with wood residues.

The Ontario Ministry of Energy through the Bilateral Program* has assisted us with a significant portion of the capital costs of installing an Ange-Varma automatic "Bark Fuel Combustion System." The fuel for this system is the waste bark and wood scraps from local lumbermill operations. We anticipate our annual heating bill to be cut by 70%. This represents a yearly savings of over $70,000.

A totally unique aspect of this operation is the potential use of a hybrid poplar plantation to grow the necessary fuel wood. While this aspect of the operation is still in its preliminary stages, it presents another intriguing possibility for energy self-sufficiency.

This paper presents the development and implementation of these programs, along with a financial analysis.

*The Canada/Ontario Agreement on the Development and Demonstration of Renewable Energy and Energy Conservation Technologies

Introduction

Grenville Christian College is a private boarding high school located in Brockville, Ontario. It houses approximately 350 students and staff in a building complex of approximately one million square feet.

The main building, a four storey limestone structure of 400,000 square feet, was constructed in 1918. This building and the others in the complex were all heated from a central, coal-fired heating plant. Coal was the energy source for fifty-three years, until in 1971 the Ministry of the Environment requested, for air pollution control reasons, that we switch to oil.

This building was highly inefficient in its use of energy, and our increasing energy awareness, along with rising costs, prompted us to begin to look for solutions to our energy problems.

This main building has stone, brick and plaster walls, with no insulation, and had no insulation in the roof. It also had large, drafty double-hung windows. Our first conservation efforts were to install thermopane windows, and insulate the roof. This produced a 15% decrease in oil consumption. (See appendix 1.)

The main College property covers 260 acres, which includes about 100 acres of woodlot. Renewed public interest in wood as a fuel prompted us to investigate whether this wood source could supply some of our energy needs.

Converting our oil use to an equivalent wood requirement, we calculated our need to be approximately 645 oven dry tonnes per year. (see appendix 2.) Conventional woodlot management techniques indicated that approximately 1400 acres would be required to supply this amount. Conversations with our local office of the Ministry of Natural Resources then made us aware of their work with hybrid poplar as a potential fuel.

We are continuing our investigation of the use of hybrid poplar as a means of growing the required amount of wood on a much smaller area of land. As the development of a hybrid poplar plantation is a long term project, wood residues from local lumber companies will provide a source of fuel for the present. After implementation of a hybrid poplar plantation, careful financial comparisons will be necessary to determine which source of fuel, whether waste or grown, would be most economical.

Conversations with various government departments made us aware of government programs to assist in the development of alternate energy sources. With help from our local Ministry of Natural Resources office, we made application to one of these programs, and our application was accepted as a pilot project in heating with wood.

The rise of energy management as an administrative tool necessary for the survival of any small business has led us to the formulation of our own energy policy, which we see in four parts. First and foremost, the economics involved have forced changes. With escalating oil prices causing fuel to take an ever increasing percentage of our budget, less expensive fuels, if available, were needed. Second, we wanted some control over our primary energy source to provide financial stability, and therefore avoid a volatile energy market. Third, we sought the security of being able to maintain operation of the College in the event of some crisis that could terminate an oil supply. And fourth, we valued being able to practice the energy ethic of using a renewable energy resource.

Planning Stages

Early in 1980, application was made to the Ontario Ministry of Energy, under the ***"Bilateral" Program*** for financial assistance to install an automatic woodfired boiler system.

In the spring of 1981, the Ministry of Energy gave approval of the plan in principle, with the initial portion being a feasibility study to determine costs. Advertisements inviting bids were placed in major newspapers, and a short interview was held with applicants.

A consulting engineering firm in Toronto has contracted to do this study. Their report concluded that such a project was feasible, a final contract was negotiated with the Ministry of Energy, and final approval was received from the Ministry in December of 1981. Construction began the following month, and the system was fired for the first time in September, 1982.

Wood Supply

As part of our initial planning of operations, obtaining a suitable low cost supply of wood fuel was essential. We first made an extensive survey of supply sources within a 100 km. radius of the College. In each case, two types of wood waste were available. Sides from the milling operations are sent through a chipper and blown into a trailer. These are then marketed for use in the paper industry. Although handling of this material is excellent, a cost of approximately $50 per oven-dried tonne was prohibitive.

A majority of the mills are experiencing difficulty with waste disposal from the debarking phase of their operations. This waste was usually being piled on vacant land in close proximity to the mill. This residue contains percentages of sawdust, wood pieces and bark. The bark, especially long stringy sections, caused difficulties in handling. These pieces can clog the system at junctions of the various augers. The addition of a hogging system or a classifier at the mill is necessary to alleviate this problem. This hogged residue is presently being used at the College.

Eventualy, these sawmills were approached and asked to submit bids for a one year contract to supply the College with 33, 50, 66 or 100% of the annual fuel requirements of the College. Two mills were chosen to supply fifty percent of the annual requirements each. This was decided upon to insure us against labour disputes, inclement weather, vacations, equipment failure or anything that might interfere with the continual flow of fuel. We felt that it was important to strive for the same type of convenience that regular oil deliveries entailed. In this regard, the mill operators and their commitment to the projects was very important in our decision. It is important that the supplier is aware of the innovative nature of the project and is willing to be part of it in order to work out problems that will arise in the initial stages of operation.

Sawmill operators normally supply chips and sawlogs at a fixed price per tonne set by the large paper mills. When the operators submitted their bids, they discussed the various price components of their bid, qualifying the cost of transportation, capital expenditures, and material costs. It became obvious that the transportation cost per oven dried tonne is the critical factor. Since the demand for this waste is still small in this area, mills could not justify purchasing large (40'-45') self-unloading trailers. Therefore, transportation costs were higher because of the smaller volume transported in a lower volume trailer.

In Eastern Ontario, a substantial forest industry infrastructure does not exist. In other areas where the forest industry represents a major factor in the local economy, large trailers would already be available. Also, the sources of wood residue would be more numerous and in closer proximity to the heating system. In our case, the suppliers deliver from 100 to 50 kilometers respectively.

When each delivery of wood residue is received at the College, a representative sample is taken. The sample is weighed and dried according to standard procedures (24 hours at 102°C) to determine percent dryness. The price of the material is given per oven dried tonne. Our costs per oven dried tonne average are $30.00.

Wood Burning Heating System

The system as installed includes the following components:

1 Fuel storage and handling system

2 Furnace and gas handling equipment

3 Heat exchanger

4 Ash removal system

5 Electrical control panel

Fuel Storage and Handling System

The waste wood fuel is delivered to the underground storage silo by dump truck and conveyed to the furnace by means of a system of hydraulic scrapes and rotating screw conveyors. The fuel is fed into the furnace by a screw conveyor which runs underneath the heat exchanger (boiler) and the combustion chamber where it falls onto special conical stop grates.

Furnace and Gas Handling Equipment

The furnace is basically a large steel box lined on all sides and top with four inches of high temperature insulation and six inches of special castible refactory material. There is an opening on one side of the furnace which allows the hot exhaust gas from the fire to flow into the heat exchanger. From there the exhaust gas is cleaned by passing through a fly ash collector which removes the fine ash before it is exhausted to the outside air by way of the smoke stack. This fine ash is injected into the ash removal system. The rate of burning is controlled by the demand on the system and the flow of fuel is automatically monitored by a number of sensing devices located at specific locations at fuel transfer points.

The quality of the fire depends on the correct quantity of air flowing through the furnace to provide complete combustion of the fuel. This is achieved by means of fifteen H.P. induced draft fan and a damper which automatically operates to provide the optimum conditions.

Heat Exchanger

The heat exchanger is positioned next to the furnace and is comprised of a standard fire tube low pressure water boiler which has been modified for use with the wood burning system. It is capable of producing a maximum of five million BTU's of heat per hour. In the event of any disruption to the fuel supply, the boiler can also be fired using oil.

The boiler is equipped with all necessary control devices to ensure completely safe operation.

Ash Removal System

It is necessary to periodically remove ash from the furnace and this is done by switching the system to standby, opening the fire doors of the furnace where it is removed automatically by a system of screw conveyors to an ash cart outside the boiler house.

Electrical Control Panel

The entire heating system is automatically monitored and controlled at the control panel which provides a graphic display using illuminated devices of all operations of the system. By means of overload protection devices, relays, timers, and control modules any fault that may occur in the system is detected and the system automatically shut down until rectified.

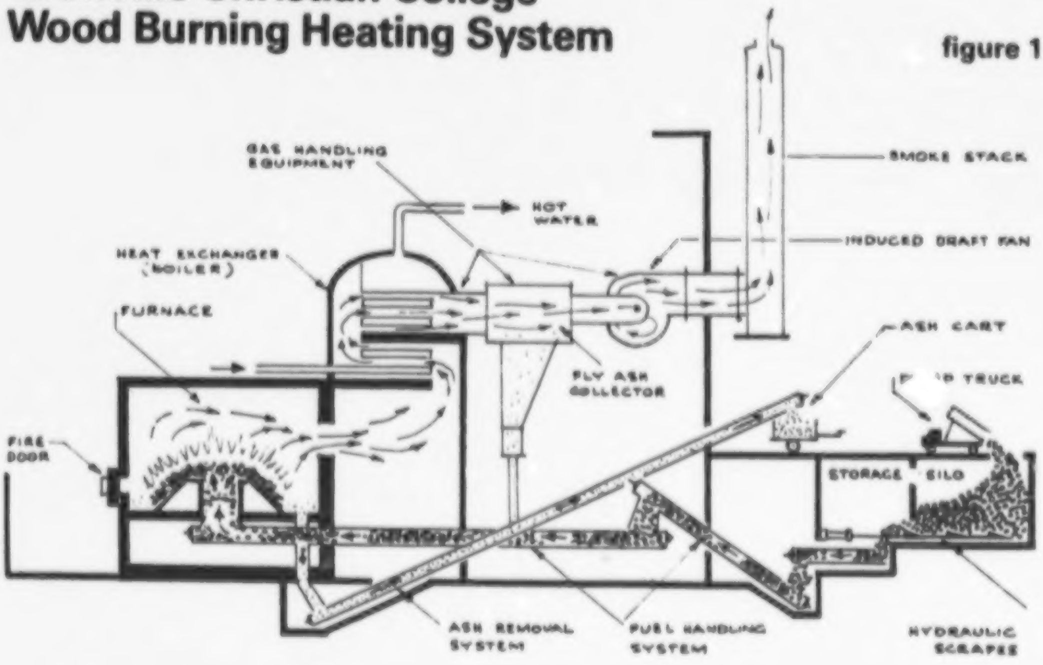
The outline sketch in figure 1 shows the components of the system.

Financial Analysis

Since the 1976-77 heating season, consumption of oil has stabilized at approximately 68,000 imperial gallons (see appendix 1). Converted into wood residue, this represents 645 oven dried tonnes (see appendix 2) at an average cost of $30.00. Our fuel costs for 68,000 imperial gallons should be approximately $19,350.00 This represents a substantial reduction in annual fuel costs. Presently (September 1982), the cost per imperial gallon of number two bunker oil is $1.43 per imperial gallon. This would represent an oil payment of $97,240.00 on our fuel bill. This represents an annual savings of $77,890.00. The expected simple payback based on the final costs of the project of $360,000 and using the present price of oil as a benchmark would be 4.6 years. The total calculation can be found in appendix 3.

Grenville Christian College
Wood Burning Heating System

figure 1



OUTLINE SKETCH OF SYSTEM

Project Summary
Automatic Wood Heating

Project Location:
Brockville

Date:
October 20,1982

Technology:
Automatic Wood Burning System

Project Managers:
Mr. D. Ortolani
Mr. F. Wood
Grenville Christian College
or Box 610
Brockville, Ontario K6V 5V8
(613) 345-5522

Project Number:
6788

Sector:
Institutional

Status:
Construction
Complete

Province:
Ontario

Purpose:
To demonstrate a fully automatic wood fired heating system which will supply heat to school buildings.

Description:
The project involves the installation of a 5 million BTU/hr. Anga-Varme fully automatic wood burning system. It will supply hydronic heat and domestic hot water for the College.

Contributors:

Grenville Christian College	$ 40,000
Anga-Varme Ltd.	$ 18,000
Canada/Ontario	$384,000
TOTAL	$442,000

Expected Benefits Savings:
Savings of 76,000 Imp. Gals of No. 2 fuel oil per year (2,200 barrels of oil equivalent (BOE)).

Further Information:
Grenville College has invested $175,000 in a farm on which it will grow hybrid poplar in order to eventually make the school self-sufficient in energy. A slide show has been produced which highlights the construction phases of the project.

Information Contact:

Rev. Alistair Haig
President
Grenville Christian College
Brockville, Ontario
K6V 5V8
(613) 345-5522

R.W. Houldin
Project Leader, Forest Resources
Renewable Energy Group
56 Wellesley Street West
Toronto, Ontario M7A 2B7
(416) 965-8424

Economic Analysis:

Project costs (1981$s)

Capital*	$177,100
Installation	$172,900
Total installed cost	$350,000
Monitoring and technology transfer	$ 82,000
Feasibility Study	$ 10,000
Total demonstration cost	$442,000

*Equipment

Operating Costs

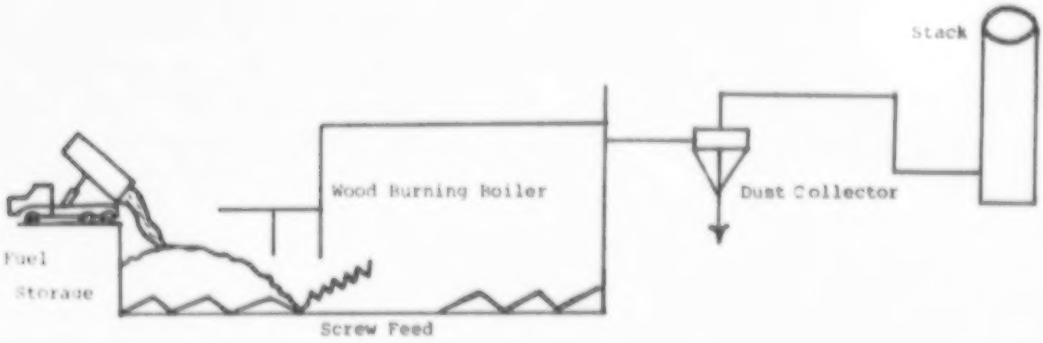
Pre-demonstration annual fuel cost (76,000 BOE at $1.33 per gal)	$101,000 (1982)
Post demonstration annual fuel cost (1000 oven dry tons of wood at $30/ODT)	$ 30,000
Net annual fuel savings (1750 BOE)	$ 71,000
Simple Payback Period	5 years

Monitoring/Evaluation:
The system's operating and down times will be logged. The efficiency (mass energy balance) of the system will be evaluated. Emissions testing will also be undertaken. The monitoring program will be conducted over a six month period.

Technical Details/Specifications:
Anga-Varme woodburning system, complete with fully automatic wood handling and feed system, fuel cell and boiler, rated at 5 MM BTU/hr., producing 15 PSI steam.

Initial Fuel: hogged mixture, 1/3 sawdust, 2/3 bark and chips
Eventual Fuel: hybrid poplar whole tree chips

Schematic Diagram:



Appendix 1

	July 1, 1976-June 30, 1977	July 1, 1977-June 30, 1978	July 1, 1978-June 30, 1979	July 1, 1979-June 30, 1980	July 1, 1980-June 30, 1981	July 1, 1981-June 30, 1982
Main Complex	81,781	68,984	67,399	68,903	65,039	64,657

Appendix 2

Cords to Cubic Metres

1 cord (4' x 4' x 8') = 3.88 cubic metres (stacked)
= 2.606 cubic metres (solid wood)
(note: 1 cord = 85 cubic feet solid wood)

Cord to Oven Dry Tons & Energy Equivalents

Depending on species, wood varies considerably in weight. The following factors are based on Ontario weight sampling over a broad range of conditions:

Species	ODT/Cord	Gal. Oil/ Cord	M^3Oil/ Cord	BTU/Cord (Millions)
Spruce & Jack Pine	1.126	118	.536	18
Poplar	1.381	145	.659	22.1
Mixed Hardwoods	1.615	170	.773	25.8

The above conversion to energy equivalents assumes a BTU rating of 8,000 BTU/lb. for oven dry wood. Specific analysis will require adjustments for efficiency depending on variables such as moisture content of feedstock, boiler design and heat transfer system.

Appendix 3

Financial Analysis

68,000 imperial gallons replacement by woodchip svstem presently. 1 imperial gallon equals 167,000 BTU

$68{,}000 \times 167{,}000 = 1.14 \times 10^{10}$

$1.14 \times 10^{10} \div 8{,}000$ BTU/lb. = 1,419,500 lbs. of oven dried wood

1,419,500 ÷ 2,200 = 645 oven dried metric tonnes

645 x $30.00 = $19,350.00 replacement cost for 68,000 gallons of oil

68,000 x $1.43 (price per imp. gallon of oil as of Sept. 1982) = $97,240.00

$97,240.00 – $19,350.00 = $77,890.00 annual savings

$360.000.00 ÷ $77,890.00 = 4.6 years as a simple payback.

Residential Central Heating Systems Using Forest Wastes

by:
R. J. Brandon
IEA Consulting Group Ltd.
71 Water Street
Charlottetown, P.E.I.

Abstract

The rapid growth in wood heating in Atlantic Canada has included a shift towards wood fired central heating systems in the residential market. This factor and the associated concern for the impact on the forest resource of fuelwood use has resulted in the development of demonstration programs on the use of wood chip and wood pellet fuel in Newfoundland, Prince Edward Island and New Brunswick. A summary of the projects and the problems and advantages discovered in the use of forest residues in small scale combustion systems will be discussed with particular emphasis on fuel delivery systems and costs.

Introduction

Since the introduction of the Federal Government's COSP program there has been a significant increase in the number of wood heating systems that have been purchased compared to previous years. For the quarter ending March 1982 Statistics Canada estimated that Canadian manufacturers shipped 12,300 wood burning units of which 22% were central heating systems. Information from the CREO offices of EM&R in the Atlantic region indicates a significant increase in grant requests related to wood heating systems. There appears to be an increasing trend towards central heating systems as people try to obtain as much convenience as possible from a wood heating system.

The existing wood heating systems use blocked and split round wood as the form of wood fuel. Because the total fuel load is located within the combustion chamber the heat output of the device has to be controlled by limiting the amount of combustion air admitted to the fuel charge. Incomplete combustion of the heated wood fuel charge results in creosote deposits in the flue and the consequent risk of chimney fires.

An alternative approach to the combustion of wood fuel would be to feed particle wood into the combustion chamber by means of a feed mechanism whenever the combustion system is on "high fire". In this way the combustion process could be more closely controlled and combustion efficiency significantly improved.

The use of chipped wood as a heating fuel in small houses was common in Northern Europe in the early 1950's. During the following decade, when oil was inexpensive, usage declined. The interest in chipped wood as fuel revived after 1973 and Sweden, Finland and to a lesser extent, Norway and Denmark, continue to have an interest in the use of chipped wood fuel for heating residential houses. This body of experience is well described in[1,2] and formed a basis for experimental programs in P.E.I., New Brunswick and Newfoundland.

The reason for the activity in these provinces was due to a number of factors including:

a) a reliance on imported oil;
b) access to low cost wood;
c) existing experience in the use of wood fuel in residential housing;
d) agencies and individual researchers interested in the fields and;
e) federal and provincial funding support.

Close co-operation has been achieved between the project teams working in the Atlantic provinces which has proved beneficial.

The next sections describe the activities in each province in the areas of residential chip wood and pellet wood combustion followed by discussion and overall conclusions.

Prince Edward Island

The Institute of Man and Resources acting as agent for the Canada – P.E.I. Agreement on Renewable Energy decided, in 1979, to carry out a series of demonstrations and experiments in the area of residential wood fired central heating. A demonstration of ten central heating systems included four chip burners from the Swedish companies Palmia, Skogma, and Anga and Varme. A coal stoker from Will-Burt was used to burn wood pellets. This work, which was carried out over the winter of 1979/80, indicated that the use of waste wood, in the form of chips and pellets, offered advantages over roundwood in terms of operator convenience and comfort. The results of this work are published in[3] and summarized in[4] and[5].

Following this project it was decided to carry out a large scale demonstration with the following objectives:

a) to demonstrate the feasibility of residential wood heating using non-merchantable forest residues as fuel;

b) to determine optimum methods of chip wood fuel harvesting, processing, delivery, storage and distribution;

c) to develop a preliminary commercial infrastructure to support chip and pellet wood fuel supply systems for the residential sector; and,

d) to compare operating experiences with both types of particulate wood fuel, chips and pellets.

The project was designed to have two separate components, each dealing with the different wood fuel forms, wood chips and wood pellets.

Wood Chip Demonstration

This sub-project installed thirty (30) wood chip fired systems in rural homes. One condition was that the property had to have access to a woodlot of 10 hectares or more and a woodlot management plan certified by the provincial forestry department. Preference was also given to groups of two or more homeowners living within a ten mile radius of each other.

Previous experience had suggested that the use of chipwood would be most appropriate in rural or farm sites where covered storage for fuel chips was available. Urban sites were considered more appropriate for pellet wood systems.

Fuel Storage

Homeowners were allowed up to $350 for materials in order to construct a chip bin to prescribed specifications, which included the installation of perforated ABS pipe on the storage space floor. A small blower could be connected to the pipe to ventilate the pile if necessary.

Combustion Equipment

Because hardware cost of any new technique is very important in the speed of subsequent adoption it was decided to use a simple gravity feed preheater, similar to the Skogma unit that had previously been tested, rather than the more complex and expensive stokers. A local Charlottetown company, Saturn Corporation, manufactures the preheater as the "Firefly" unit, rated at 30 KW (100 M BTU/hr). In the project the preheater was connected to three types of Maritime boilers and furnaces, the Kerr Titan, the Fawcett WF 200 and the Corrigan PatLyn.

Fuel Supply

In the first year, 1980/81, the supply of fuel chips was contracted to the P.E.I. Woodlot Owners Association. The intention was to obtain cost data to determine the feasibility of small contractors supplying rural homes as well as educating the homeowners in the use of the chipping equipment. The project acquired a Bruks 723 tractor driver chipper imported by BDR Machinery Ltd. of Mississauga. The homeowner, in all cases, supplied the tractor and farm vehicles to transport the chips.

Because harvesting occurred late in the year only dead softwood was cut and chipped using a crew of 2-3 cutters and a supervisor/chipper operator. Time records were kept and the results are shown in Table 1. Each house had approximately 50 m³ of chips produced.

Wood Chip Fuel Production

Table 1

Activity	Mean (man hrs.)	Standard Deviation (man hrs.)
Cutting	53.9	33
Chipping	14.9	9.4
Winching & Hauling	18	10
Storing	8.9	8.4
Travel	24	15.6
Unproductive	21.8	18.8
Homeowner	15.6	13.6
Total hrs.	157.1	81.6
Total productive hrs.	135.3	

Average site production 48 m³ fuel chips.

Compiled from data in[6]

The conclusion, from the 1980/81 season, was that a small woods contractor would find it difficult to make money supplying wood chips to small homes because of the high labour activity involved.

In the second year, an arrangement was made with a Charlottetown rental company to rent the chipper to homeowners. The rate was set at $30/day for the Bruks 723. In order to have a back up and because a large number of the homeowners expressed interest in a self powered chipper, a Morbark Eeger Beever with a four knife disc was obtained. This unit powered by a 60HP gas engine has a throat opening of 12" and powered feed rolls. Unfortunately, the unit could not reliably produce the uniform and small fuel chips (10 x 12 x 3 mm) needed for the gravity fed preheaters. Morbark carried out extensive testing to reduce the chip size to that produced by the Bruks but without success. It should be noted, however, that chips produced by the Morbark unit might be suitable for a stoker fed unit. The homeowners' reaction to the two units was an overwhelming preference for the self powered unit even at its higher rental cost of $60/day. This was because of its powered feed rolls and higher chipping capacity.

Maintenance of the chippers proved to be a problem since the machinery was unfamiliar to the rental company's mechanics and the use of the machines was low compared to other equipment rented. Knives were surface ground after each rental and the high cost of this at $18/set proved a concern to the company. Several failures of the power take-off shaft used with the Bruks occurred due to poor maintenance procedures. A total of 1235 m³ of chips were produced using the Bruks chipper with a mean of 48 m³ per household.

Due to the severity of the winter, the limited indoor storage available and the high fuel consumption of the gravity fed preburner, most homeowners ran out of chipped wood in February and March. They reverted to oil or round wood for the balance of the heating season.

For the 1982/83 heating season it was decided to continue to rent the Bruks chipper but the agency was changed to one of the homeowners who was very familiar with the machine. This homeowner had assisted the rental company in maintaining the chipper the previous season and expressed a strong interest in making a small business out of renting the chipper, supplying chips and perhaps also selling and promoting chip burners. At this time the Institute of Man and Resources and IEA Consulting Group have no direct involvement with the chipper or its scheduling, the operation being completely in the private sector. The rental of the chipper is now $40/day and as of mid-November twenty of the thirty homeowners have chipped and stored their fuel. A few will be using round wood and some others, sawdust. Maintenance of the chipper is reduced although the rental fee is still too low for profitable operation and should be increased to $60. Homeowners cut and stack their wood close to their storage area and then rent the chipper for a day. In true rural tradition labour pooling occurs between neighbouring families and the whole activity of chipping is normally completed in one day.

Due to the storage limitations, hardwood is being chipped increasingly rather than softwood cleanings although homeowners recognize that either can be used. Some heating of wood chip storage has been reported but the use of small blowers to ventilate the pile has always proved effective. The homeowners continue to indicate their preferences for a self-powered chipper with a larger throat opening than the Bruks.

Homeowner Attitudes

In order to determine the attitude of the homeowners to the chip burner system and to identify problem areas, a visit to each house site was carried out during the winter of 1981/82. A 1-2 hour kitchen table discussion was held with each family, the interviewer being the same in each case. Findings from this activity were as follows.

a) The majority of the homeowners (86%) were satisfied with the system.
b) The production of domestic hot water from the central heating system was considered unsatisfactory in many cases.
c) A minority expressed concern over the dust and ashes created when servicing the units.
d) A few homeowners reported blow backs from the chip burner when the chip feed hopper was exhausted.
e) Eighty (80) percent of the homeowners expect to heat their homes entirely with wood chips in the 1982/83 heating season.
f) No homes reported any unusual allergy or health related problems using wood chip fuel.
g) Seventy-five (75%) percent of the homeowners indicated that $2000 – $3000 for a chip burner system would be acceptable, the remainder estimated $1000 – $2000.

It is recognized, that because the project is perceived as an experiment, that the favourable attitude to the equipment may be due to this factor. However it has been noted that six Firefly units have been sold in homes near participants in the program which is one indication of a continuing impact.

Wood Pellet Demonstration

From earlier work it had been concluded that wood pellet fuel was ideally suited to urban or suburban residential dwellings due to the reduced storage requirements for the fuel. The storage requirements for various fuels are shown in Table 2.

Typical Energy Densities for Biomass and Fossil Fuels

Table 2

	GJ/m³	
Wood Chip (20% MC)	3.7	(a)
Woodex Pellets (10% MC)	11.2	(b)
Bituminous Coal (5% MC)	18.4	(b)
Furnace Oil	39.2	(b)

a) Hardwood Chip Fuel (ref. 2)
b) Salter *"Production of Fuel Pellets by the Densification of Biomass"* Energex 82 Regina, 1982.

The pellet furnaces were therefore restricted to the urban areas of Charlottetown and Summerside.

Combustion Equipment

At the time of starting the demonstration the only equipment available to burn pellet fuel were modified coal stokers. The Institute of Man and Resources had had good experience with the Will-Burt 24 FA warm air hopper fed furnace, so 24 systems were installed in 1980/81. The equipment has proved reliable in the main with most problems being related to pellet fuel quality rather than equipment failure. More details on the equipment are given in.[7]

Fuel Supply

The demonstration originally intended to acquire pellet fuel made locally by an alfalfa dehydration plant. However, production problems prevented this and pellet fuel was trucked in from a Woodex licensee in Lincoln, Maine. During 1980/81 and 1981/82 the fuel was stored at a disused fertiliser plant just outside Charlottetown. Conventional feed trucks equipped with pneumatic delivery systems were used to deliver pellet fuel into bins located in the house basements. As reported in[7] the problem of dust escaping into the house proved problematic.

By the end of the 1981/82 heating season it had been concluded that the best delivery system was:

a) a once a year delivery to the site of 7-11 tonnes of material;
b) direct shipping from the production plant to the house to reduce handling costs and fuel degradation; and,
c) the use of existing basement windows as large area vents to avoid pressure build up in the fuel bin and dust incursions in the house.

It should be noted that once a year delivery to residential homes should be attractive to pellet production plants since sales can be maintained (perhaps with some discounting) through the summer months. This would allow winter production to go to predominately industrial or institutional users.

During the 1981/82 heating season the cost of pellet fuel delivered is shown in Table 3.

Pellet Fuel Cost Breakdown: Table 3

	$C/Tonne
Pellet Fuel Cost FOB Lincoln, Maine	73
Transport Lincoln-Charlottetown 530 km	33
Delivery Cost in 10 tonne loads	18
	124

The homeowners paid $100/tonne for the fuel and the project subsidized the transport cost.

During the 1981/82 heating season a total of 178 tonnes of pellets were used, each house having a mean consumption of 8.5 tonnes.

During the 1981/82 heating season three homeowners withdrew from the program citing dust and fuel quality related reasons.

Homeowner Attitudes

An interview activity similar to the one described in the wood chip program was carried out with the following findings.

a) The storage capacity of the fuel bins ranged from 4.5 tonnes to 10.9 with a mean of 7.8 tonnes.
b) Overall, three homeowners were found to be ***very-satisfied***, nine were ***satisfied***, four were ***not certain***, one is ***dissatisfied*** and three are ***very dissatisfied***. (The latter three subsequently left the program.)
c) Homeowner concerns included:
   - pellet dust in basements;
   - amount and frequency of maintenance;
   - insufficient domestic hot water;
   - insufficient heat during cold weather; (fuel quality related)
   - cost of pellet fuel;
   - quantity of fuel used;
   - smoke emissions during cleaning; and,
   - slow heating response.
d) Nine homeowners reported burnbacks through the auger systems when pellet storage in the fuel hoppers was low or during power failures.
e) Most homeowners cleaned out ash once daily during cool weather and twice daily during cold weather. Thirteen homeowners reported auger shearpin breakages due to foreign objects in the pellet fuel supply.
f) Twelve homeowners hoped to use wood pellets to supply all their house heating and domestic hot water needs for the next heating season.

New Brunswick

The principal work in the use of wood chips for heating residential houses is being carried out by Professors Short and Schneider at the University of New Brunswick in Fredericton, N.B. They have been using stoker systems with dried chip fuel 8%-56% MC dry basis starting in 1979 .[8] Work has also been done to characterize the fungi spores present in chip wood fuel .[9] A conclusion has been reached, similar to that obtained in Scandinavian work,[10,11] that care must be taken when handling fuel wood chips. It is advisable to wear dust masks and avoid bringing dusty overgarments into the living space so as to avoid lung infections linked to spore injestion.

The original work was sponsored by the New Brunswick Energy Secretariat and in early 1982, a Wood Energy Program was undertaken, funded by the New Brunswick – Canada Agreement in Renewable Energy, managed by E.T. Owens of the New Brunswick Research and Productivity Council. Together with industrial and institutional wood chip combustion systems a number of projects specific to the residential area have been undertaken.

Wood Chip Fuel Harvesting and Distribution

The University of New Brunswick (Forestry Faculty) is carrying out a demonstration of an integrated chipping, drying and delivery system. Based on experience obtained with the chip stokers used by Schneider and Short and the finding that fungi spores are significantly reduced with dry fuel, the objective is to determine the costs of delivering such fuel chips to residences. A chip wood terminal system capable of air drying 35 m^3 of screened fuel chips is under construction. It is hoped that the facility will dry loads on a batch basis in 3-5 days. Industrial garbage containers are being used as fuel storage boxes in a chipping operation that uses a tractor driven Bruks 722 chipper. Initial results from this work should be available in late 1983.

Residential Stokers

A Fredericton company, Rundle Ltd., is manufacturing and installing six chip fired stokers in residential homes. This is part of a development program to produce a Canadian made chip wood stoker. It is planned to supply chipped wood from the wood chip terminal to the sites.

Wood Chipper Development

Arvin Special Machinery of Chatham, N.B., has developed a tractor driven disc chipper for producing fuel wood chips. It features a horizontal infeed for easy handling of small diameter material and a powerful discharge fan capable of blowing fuel chips 12 metres. This is useful when loading chip trucks.

Newfoundland

The Newfoundland Government is sponsoring a demonstration of residential chip furnaces similar to the project in P.E.I. Twenty installations have been made in suburban homes located in rural centres. The types of equipment used are the "Firefly" preheaters coupled to both boilers and furnace systems. Vented wooden chip bins are used similar in design to the storage units used in P.E.I. Some local insurance companies have expressed concern over the chip bin design requesting that the chip fuel bin be made of materials that have a high fire rating. CSA is currently developing a draft standard for storage systems for both pellet and chip wood fuel.

Fuel Supply

During the 1980/81 heating season chip wood fuel was provided using local woods contractors. A Bruks 723 chipper was used with a 60 H.P. tractor with trees felled using a two man team. The average cost of producing the chip fuel at a landing was found to be $46/green tonne. The delivered cost was $77/green tonne.

It is interesting to note that in the P.E.I. demonstration the total cost of the contractor wood chipping project in the first year was $55,600, which produced about 660 green tonnes of fuel chips at a total project cost of $83.6/green tonne.

During the 1982/83 season the chipper is being scheduled by the project along with a chipper technician. The homeowner is expected to assist in acquiring the wood and storing the fuel chips.

Small Institutional Buildings

It is anticipated that three SVEMO chip stoker preheaters of 250,000 Btu/hr rating supplied by BDR Machinery of Toronto will be installed in commercial or institutional sites during the 1982/83 heating season. These sites will be supplied by the same woods contractor who supplies the residential sites.

Nova Scotia

Two farms in Canning, Nova Scotia, have installed wood chip fired central heating systems that heat the farm house as well as providing hot water and heating to barns.

One site uses three "Firefly" units installed in a new boiler room/storage facility. The storage facility has a floor area of 280 m^2. Underground insulated hot water lines connect the heating system to the house.

The other site has installed a larger version of the residential preheater rated at 150 KW (0.5 MM BTU/hr). This central heating plant serves two chicken barns and two houses using insulated underground lines.

Further information on this project is given in.[12]

Discussion

Chip Fuel

In the residential and small commercial sector there is no doubt that potential purchasers of a chip fuelled heating system are deterred by uncertainty as to their source of wood fuel. This is attested to by the fact that the majority of recent purchasers of the Saturn "Firefly" units plan to use sawdust as a fuel since they are sure of their local source. In New Brunswick and P.E.I. it is possible to rent a tractor driven chipper but because these units are government owned the public is unsure as to how long the machines will be available.

The possibility of renting small chippers through an established rental company is attractive but potentially premature at this stage of development. Experience in P.E.I. and New Brunswick has shown that maintenance by experienced personnel is needed for good equipment performance. Renting the chipper through a small woods contractor who could use the equipment in his own business appears to be the most attractive option at this time. Agencies interested in promoting the use of waste wood in small scale combustion systems should recognize that investing in the harvesting system would prove beneficial in encouraging conversions especially if the availability of the chipper were promoted. A problem with renting this type of equipment is the fact that the majority of the chipping activity occurs in the autumn. This seasonal use makes it difficult for a rental company to rationalize purchase of a chipper; a small contractor might use the chipper during other seasons of the year in cleaning operations.

The experience in P.E.I. and Newfoundland indicates that the contractor cost of supplying wood chip fuel to homes is as high or higher than the comparable cost of round wood fuel, being in the region of $100 a cord. However, if the homeowner undertakes the wood chip fuel supply responsibility then his out of pocket costs become comparable to the costs he would incur if he was cutting and splitting round wood. These out of pocket costs for renting the chipper, renting a tractor and supplying fuel might total $200 for one day. This processing cost is therefore equivalent to a premium of $20 per cord of processed fuel assuming an equivalent of ten cords are chipped.

Wood Pellet Fuel

The requirement for a large production facility for densified fuel means that reliability of fuel supply becomes a critical factor in regard to implementation of wood pellet fuel use in the residential sector. At present it would appear that the processing cost for densified fuel from a large plant of 80-90,000 tonnes annual production ranges from $25-30 per product tonne. Taking whole tree chips at $50/O.D.T. this would yield pellet fuel FOB the plant at approximately $80 per tonne. Experience in P.E.I. has shown that delivery costs excluding bulk shipping will probably cost $18/tonne in small quantities. Bulk shipping costs appear to be costing $0.077 tonne/km (current cost of shipping pellet fuel from Lincoln to Charlottetown). Taking a shipping distance of 200 km this would cost $15 per tonne yielding a total delivered cost to a residence of $113 per tonne. This gives a delivered cost of $6.0/GJ for wood pellets compared to $7.5/GJ for light fuel oil.

There do not seem to be any major technical difficulties in delivering pellet fuel to residences or small businesses in urban or suburban areas. The difficulties reside in obtaining fuel pellets of good quality at a sufficient price differential with fuel oil. The small commercial/industrial and institutional sector would appear to be more cost effective since the larger fuel volumes used increase fuel saving while the capital costs of the combustion equipment should not increase to the same extent. For example, a home using eight tonnes of pellet wood would displace about 4000 litres of fuel oil and create fuel savings of $460 taking a fuel oil cost of $0.34/litre.

Other work in the field of conservation[13] has indicated that homeowners will not consider investments that exceed a simple payback of five years. Using this criteria, it would appear that the pellet furnace and storage silo should not cost more than $2,500 installed. At the present time the furnace or boiler and storage would cost closer to $4,000 installed allowing $2,500 for the furnace, $1,000 for installation and $500 for the storage bin. This gives a 8.8 yr. simple payback. Government programs such as COSP would reduce this payback time.

However, the biggest uncertainty in the homeowner's mind must be the reliability of the fuel service. The experience of the P.E.I. project has been that the reliability of fuel supply has been low, with the Lincoln, Maine, planting suffering a site fire and at least one refinancing. These uncertainties are to be expected in the development of a new fuel type and mirror the difficulties that fuel oil had in replacing coal as a residential fuel a few decades ago. The savings that accrue to the homeowner must increase significantly before this fuel will make inroads into the residential sector. The most attractive market for the fuel at this time is small commercial or industrial installations located in rural areas within 200 km of the production plant. The possibility of a future connection to the natural gas system is also a significant disincentive to decision makers considering pellet fuel.

Equipment Standards

A sign that the technology is approaching commercialization is shown by the fact that the Canadian Standards Association funded by EM&R, is developing test methods and draft standards for combustion systems and fuel storage methods for chip wood and pellet wood. Concerns have been raised by insurance authorities over the lack of standards on wood chip and pellet storage and these are being addressed by the CSA committee.

The current lack of CSA certification for any chip burner is a definite market deterrent to significant commercialization.

Conclusions

The work that has been carried out in the Atlantic provinces has shown that chip wood has a definite potential as a substitute for round wood fuel in rural areas. At the present time there are several major barriers to increased utilization but none of them appear insurmountable. The barriers are:

- uncertified combustion systems;
- lack of standards for fuel storage; and,
- potential health hazards from wood fungi spores.

The first barrier, that of uncertified equipment, requires only time to become resolved as potentially, chipfired equipment should be safer than creosote producing roundwood equipment. The second and third barriers suggest the conclusion that at this development stage the farm sector is the best location for wood chip combustion systems, especially when the boiler house and storage can be separated from the residence. The familiarity of farmers with mechanised processing equipment and access to nearby low cost wood together with their resourcefulness in using existing equipment suggest a good match with this developing technology.

The future for pelletised wood is less clear because of the requirement for a centralized plant and the low cost differential at the present time between conventional fuels and pellet fuel delivered to residences. It should be noted that this conclusion is based on pelletised fuel using whole tree chips as a feed stock rather than the residues currently being used by pellet production faclities. Demand for residues may become very severe when the wood product industry revives since it can be used in hog fuel boilers or as a feed stock for wood products such as particleboard. Thus, any large-scale conversion to wood pellet fuel in the residential sector should be evaluated on the basis of whole tree chips being used as a feed stock. In P.E.I. a concept that is being explored is a pelletising facility that is capable of processing a great variety of feed stocks such as alfalfa, corn, cull potatoes as well as wood. This would reduce the initial wood pellet production to about 10-15,000 tonnes a year from a 50,000 tonne/yr capacity plant. The smaller production would enable residential and commercial conversions to be made in more reasonable numbers than required if a larger dedicated plant were to be built.

The security of fuel supply is the largest barrier to implementation in the residential sector, and this can only be overcome over time. At the moment it would appear that the most promising residential market exists in urban centres in rural areas within 200 km of the existing plants in Ontario and Quebec presently serving industrial customers.

The rate of implementation of a new fuel type such as wood chips and wood pellets is slow as many technical, economic and institutional barriers have to be overcome. However the demonstration projects in the Atlantic region have solved some problems and indicated others. The very existence of the projects has started bodies such as the CSA and the insurance industry to consider questions raised in the demonstrations. Implementation is expected to be an increasing trend driven on principally by the perceived cost differential between conventional fuels and the new processed wood fuels. The availability and cost of round wood fuel will remain an important factor.

References

1 Beijbom & Nilson "Fliseldning for Gardar Och Smahus" (Chip Heating for Farms and Small Houses), **Silviconsult Ltd.**, 23050 Bjarred, Sweden.

2 Hermelin, Schneider and Short, Wood Chip Heating of Homes and Other Small Buildings **Department of Energy, Mines and Resources**, Canada, January 1982.

3 Island Energy Associates, Wood Fired Residential Heating Demonstration, **Institute of Man & Resources**, August 1980.

4 R. J. Brandon, Residential Wood Fired Furnaces: A Demonstration of Advanced Systems. **Energy from Biomass and Wastes**, Institute of Gas Technology, Chicago, January 1980.

5 R. J. Brandon, An Assessment of Efficiency and Emissions from Ten Wood Fired Furnaces, **Wood Energy Institute Conference**, New Orleans, 1980.

6 Island Energy Associates, Wood Chip Fuel for Residential Use, **Institute of Man & Resources**, November 1981.

7 Island Energy Associates, Wood Pellet Fuel for Residential Use, **Institute of Man & Resources**, November 1981.

8 C. A. Short, Home Heating with Wood Chips, **Residential Solid Fuels Conference**, June 1981. Oregon Graduate Centre, Beaverton, Oregon.

9 J. D. Miller, M. H. Schneider and N. J. Witney, Fungi in Fuel Wood Chips in a Home, **Wood and Fiber** 1982 14(1). 1982

10 Thomas Thornquist and Hans Lundstrom Svampforekomst vid Bransleflis-Lantering I Mindre Anlaggningar, (Factors Affecting the Occurrence of Fungi in Fuel Chips for Domestic consumption), **Skogsenergi** Nov. 18, 1980 re Project 3065 121.

11 Helge I. Hoeg, Forekomst Av Soppsporer I Forbindelse Med Flistyringsanlegg Og Lagring Av Flis (Presence of Fungus spores in connection with Wood Chip Heating Plants and Wood Chip storage) **Norsk Institute for Luftforsking,** P.O. Box 130, 2001 Lillestrom, Norway.

12 Project Summary, Barn Heating Using Wood Wastes **Pilot Projects Program** N.S. Dept. of Mines and Energy, P.O. Box 668 Halifax, N.S. B3J 2T3.

13 Stobaugh, and Yergun, **Energy Futures**, 1979 Random House.

Efficiency of Wood-Burning Appliances

by:
E. A. Fernbach

Abstract

A brief introduction describing an overview of the behaviour of solid fuels is given. The paper then summarizes three principal design options in relation to the combustion process. An option which is characterized by an under-supply of oxygen is then developed for a wood-burning device equipped with a catalytic combustor. The advantages related to efficiency, emissions and safety are described. The balance of the paper describes the calorimetric test method used at Ryerson Polytechnical Institute, discusses the advantages of the calorimetric method over the stack-loss method, presents comparative test data to substantiate the benefits of catalytic combustors and finally illustrates a self-contained retrofit combustor system which was designed at Ryerson.

Introduction

To establish a background for the discussion of efficiencies of wood-burning appliances the following generalities relating to the subject should be mentioned.

Solid fuels may be classified as:
Direct combustibles
Indirect combustibles
Composite combustibles

All combustibles have an endothermic initial phase of combustion. The energy related difference lies mainly in the chemical processes that make the combustion self sustaining and finally exothermic.

In this context a fuel may be loosely classified as a direct combustible solid if the combustion will progress without the remaining fuel undergoing a change of state or a change in the chemical composition. In the case of homogeneous coal for example, the carbon concentration remains more or less constant until all combustible matter is "consumed".

For a given mass and volume of the fuel-bed the combustion rate can be kept at a nearly constant level with a relatively simple air-regulation and an equally simple device to keep the fuel surfaces exposed to the combustion air and provide removal of ashes by means of a shakeable grate.

A direct combustible fuel like coal, if burned at extremely high rates (forced draft), will produce extremely high temperatures. Even though these temperatures afford a nearly complete combustion they cause the generation of highly toxic combinations of nitrogen and oxygen. Moreover, bituminous coal has the further disadvantage of relatively high sulphur concentration which not only adds to the acidity of our atmosphere but plays "havoc" with metal-chimneys. (One is therefore advised to use anthracite).

In indirect combustible solids, like wood, the chemical composition of the fuel changes. The wood itself is not a combustible, the long organic molecular chains of lignin, cellulose and others are cracked into liquid and gaseous hydrocarbons of many varieties but primarily paraffins, olefins and aromatics. During this process the carbon concentration increases until, in the final stage, only coal (that is charcoal) remains with a carbon concentration of greater than 90%, having roughly the same properties as previously mentioned. In the first stage of combustion the process is primarily endothermic where the greatest part of the supplied energy is expended in gradually evaporating the moisture content of the "skin" of the wood. The beginning of a second phase can be observed when the average temperature of the wood is above the vaporizing point of the water. The entire endothermic energy is available for breaking molecular bonds and generation of the aforementioned hydrocarbons which then become the principal sources of exothermic energy. But, for all practical purposes, the generation of these combustibles is random with enormous volume and velocity fluctuations. If the velocities of these gas-jets surpass the average flame front velocity, then the combustion front is carried off in a vortex and the combustibles escape to the chimney even in the presence of sufficient oxygen. (On the other hand a flame front propagation may collapse if the diffusion processes of the oxygen are inhibited by insufficient air supply even for very short time intervals.)

Everyone who ever studied a fireplace in action has observed the phenomenon of flames carried into the chimney, riding on a swirling column of smoke, or a flame-front suddenly collapsing onto the wood then followed again by a whispy plume of combustibles.

Composite combustibles are simply those fuels which exhibit the properties of both direct and indirect combustibles. A good example of a composite combustible is peat.

Combustion Considerations

The previous overview of some of the combustion phenomena indicates the possibility of classifying combustion systems. But as the term efficiency has been and will be used in this paper it is necessary to briefly clarify the meaning of this term.

Combustion Efficiency is the ratio of the exothermic energy made available by the combustion to either the chemical energy of the fuel (that is the high calorific value which includes the latent heat of vapours formed during the combustion) or the low calorific value of the fuel which excludes the latent heat.

Heat-Transfer Efficiency is the ratio of the energy delivered to the environment to the exothermic energy of the combustion.

Overall Energy Efficiency is the ratio of the energy delivered to the environment to the calorific value of the fuel or the product of combustion efficiency and heat-transfer efficiency. To achieve maximum overall efficiency both the combustion as well as the heat-transfer efficiencies must be considered simultaneously. If the combustion efficiency has already closely approached the theoretical limit (as is the case in a blue-flaming gas-burner) the problem is limited to heat-transfer. But in the case of wood-burning devices this is far from being the case. Three principal design options are indicated:

1. A device that supplies oxygen and fuel on demand in nearly stoichometric ratios.
2. A device that uses fuel at a given rate, oversupplies oxygen throughout the combustion process and distributes it over an optimized chamber configuration. A common example of this option is the jet-stream system. The combustion rate is kept at maximum values and the energy is stored for later release on demand.
3. A device that uses fuel at a given rate but undersupplies oxygen throughout the combustion process. The now partially burned combustion products are further oxidized by one or more of the following sub-systems:
   - a) partial or pulsed re-circulation of the effluents into the primary chamber together with additional oxygen;
   - b) introduction of a secondary or smoke chamber with separate oxygen supply;
   - c) introduction of a catalytic combustor as an after-burner with separate oxygen supply. Such a combustor can be either an integral part of the device or a retrofit to an existing device.

The Catalytic Combustor

The following discussion must be confined to catalytic combustors for purposes of this brief paper. Furthermore, the importance of this device is seen in the fact that industry has become enamoured by the possibilities of producing efficient stoves rather cheaply through the use of the catalytic combustor.

The promise that this system holds is rather impressive:

Ryerson Wood Energy Research

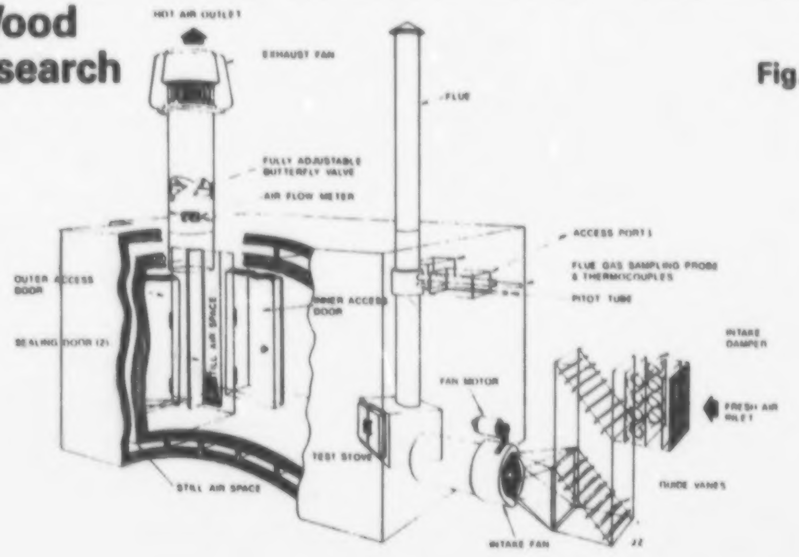


Fig. 1

1 Slow combustion is possible for fuels that outgas easily (as dry wood does). It extends the burning period and in the case of space heaters avoids uncomfortably high temperatures in the vicinity of the heater.

2 Provided the partially burned effluents can be combusted it will save considerable amounts of fuel.

3 If working properly the escape of hydrocarbons can be greatly reduced, thereby reducing the build-up of creosote and frequency of cleaning as well as increasing the safety of the device.

4 Sulphur dioxide emission becomes negligible (at the cost of deterioration of the catalyst).

5 Additional heat extraction from the combustor housing greatly increases the heat-transfer efficiency.

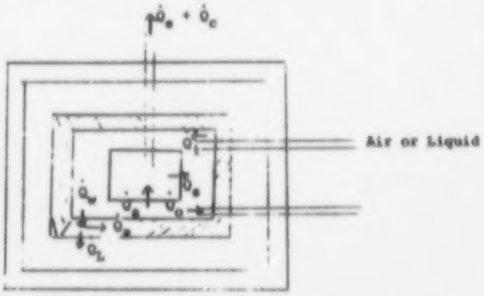
A properly designed catalytic combustor system (once it has become active) can reach combustion efficiencies comparable to the blue flame gas burners. The low concentration of hydrocarbons allows extensive heat-exchange downstream of the combustor in that the effluents can be cooled down below the dewpoint of the water vapour in the effluents. Thus the considerable amount of latent heat can be retrieved and the stack-loss almost eliminated. Overall energy efficiencies of up to 86% are feasible, though expensive.

The Calorimetric Test Method

The method of determining the efficiencies has long been a bone of contention. Thanks to the generosity of the Ministry of Energy it will be possible to apply the various methods simultaneously and come to conclusions as to their individual merits. In general, two methods are applied and used as standards i.e.:

1 The calorimetric method.

2 The stack-loss method.



The calorimetric method uses a highly thermally insulated chamber preferably thermally floating within another chamber. The medium which carries the dissipated heat of the source may be either a liquid or air (see figure).

Q_s = heat flow (power) from source into calorimeter
Q_a = heat flow from calorimeter into chimney
$Q_w = Q_R + Q_L$ = heat flow (water equivalence) of calorimeter
Q_e = heat flow of effluents
Q_c = energy loss from combustibles

In principle:
$\Delta Q = Q_o - Q_i = (Q_w + Q_a)$
Q_w is precisely established as a function of temperature and pressure in the calorimeter.
$\Delta Q = f(M_a, C_p, T,) = m_m C_p \Delta T = \rho_m V_m C_p \Delta T$
where m_m = mass flow of medium
C_p = specific heat of medium
ΔT = temperature difference of medium
ρ_m = density of medium
V_m = volume flow of medium
M_a = average effective molecular weight

ΔQ, as a function of p_m, V_m, C_p, T, p and ϕ can be measured as precisely as the measurement of temperature, pressure and humidity (ϕ) allows. The known molecular weight of air remains constant.

Q_a is measured using the difference $\Delta V = V_i - V_o$. $Q_a = p_m \Delta V_m C_p \Delta T$ for air as medium or by introducing an additional air supply in the case of a liquid medium.

The actual power output $Q_s = \Delta Q + Q_w + Q_a$ can therefore be easily established without any knowledge of $Q_e + Q_c$.

No data for combustion efficiency and/or heat transfer efficiency are obtained unless W_{fuel} is measured – which in the case of wood is questionable. The main problem lies in the excessive difference in carbon concentration of dry wood and charcoal which co-exist throughout the combustion processes.

The integral $\int Q_s dt$ of the power-output over the entire time interval or summation of integrals over subintervals yields the total energy dissipated. If the heat value of the fuel Q_f together with its total mass (and moisture content) is measured, the energy quotient of Q_s/Q_f yields the overall energy efficiency η. It may be based on either the low or high heat value. Assuming steady state conditions during the combustion process, the fuel-burning rate W can be measured accurately and the energy released would be $Q_f \simeq W\,(HV)$ where HV is the high heat value of the wood.

$$\eta = Q_o/Q_f$$

Again it must be pointed out that HV is not constant but may vary between the two boundaries of 7500 btu/lb and 13000 btu/lb between wood and charcoal.

The Stack-Loss Method

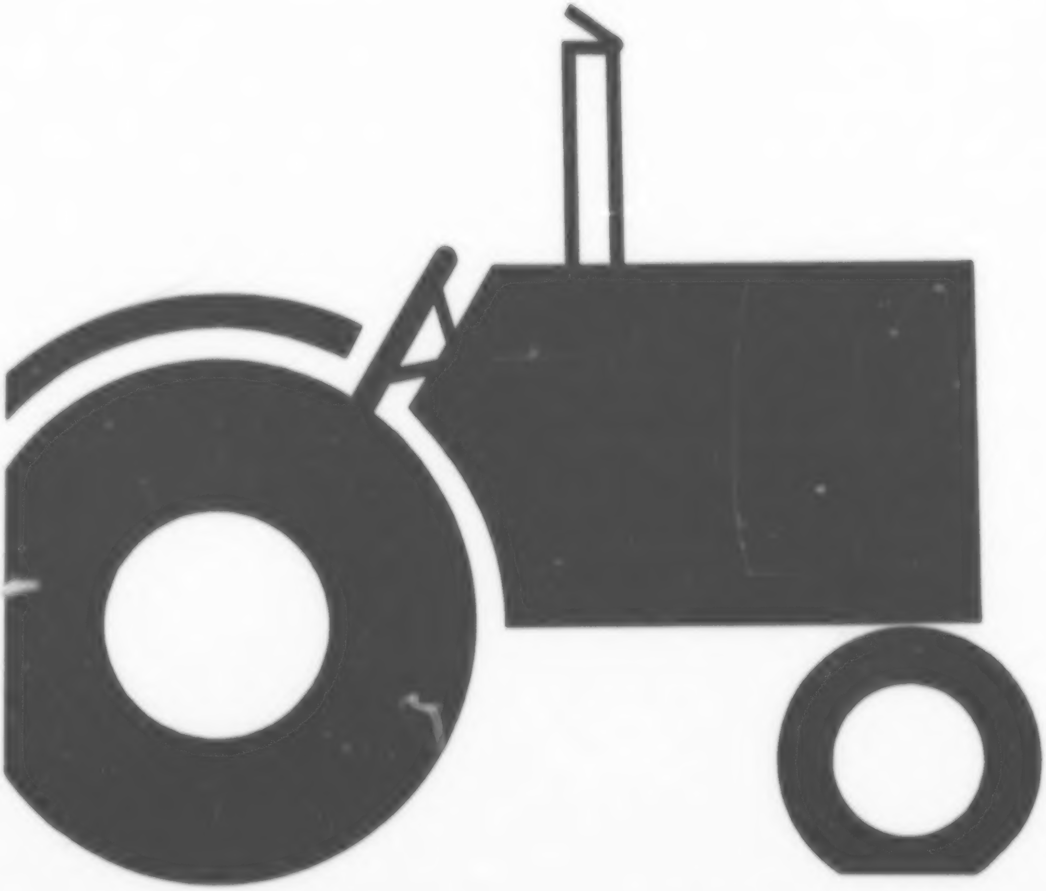
The other mainly used method is the stack-loss method. Here the energy released Q_e is measured and Q_c is approximated. Q_e requires the measurement of the same parameters but the measurement of m_e is no longer straight forward. The concentration of various gases, vapours and solids have to be measured either in batches or, preferably continuously. In wood-fires the molecular weights of the effluents vary considerably with the variations of the gas-components, water vapour and solids. Therefore the degree of precision compared to measuring Q_s is lower by more than one order of magnitude. Furthermore, the heat supplied via the combustion and excess air is very difficult to measure without the benefit of calorimetric facilities.

Further complicating matters is the measurement of Q_c which is the energy loss of combustible gases and solids, primarily CO and hydrocarbons. Generally the "total hydrocarbon" analysis is made using the ionization effect of carbon in a hydrogen flame. The concentration values measured are converted using the heat value of a particular hydrocarbon – mostly CH_4. Realizing the great discrepancy of heat values between paraffins, olefins, aromatics and other hydrocarbons one is led to the conclusion that the stack-loss method – though undoubtedly useful (at least as an excellent indicator of energy releases) – is indeed inferior to the calorimetric method in the case of indirect combustibles such as wood. It only closely approaches the accuracy of the calorimetric method for direct combustibles with quasi-constant chemical compositions.

In the final analysis, the two methods must be seen as being largely complementary.

Notes

Agriculture



Energy Considerations in Crop Production

by:
T. B. Daynard
Professor, Department of Crop Science
University of Guelph
Guelph, Ontario

The general situation and many specifics regarding energy use in Ontario agriculture have recently been reviewed and summarized in a publication entitled ***Energy and Agriculture***, written by the Ontario Energy and Agriculture Policy Committee (1981). Approximately 12% of the total energy consumption in Ontario is used in the food supply system, with about ¼ of this involved in primary food production (i.e., on the farm, and in the production of farm inputs), and ¾ used in food transportation, processing, and food preparation in the home. While the relative amount of energy consumed in primary agriculture in Ontario is, thus, quite small, the absolute quantity is still large – the equivalent of about 10 million barrels of oil per year (Pinnington 1976) and the absolute cost to farmers is also high. Energy was estimated to represent 18% of the total operating cost on all Ontario farms in 1980 in ***Energy and Agriculture***, and 34% of operating costs on farms devoted primarily to the production of crops. About $260 million was spent to purchase electricity and petroleum products for farm operations in Ontario in 1981 (Ont. Min. Agric. Food 1982); to this should be added the sizeable energy component inherent in the cost of purchased fertilizer and pesticides ($420 million). The above are put in clear perspective when compared to the value of net farm income, $835 million in 1981 (Ont. Min. Agric. Food 1982) – a value which will be substantially lower in 1982 and 1983.

In the publication, ***Energy and Agriculture***, it is estimated that 64% of the dollar expenditure for energy on Ontario farms involves costs for crop production and preservation. However this figure is based on 1978 data does not include costs for the production of tobacco – one of Ontario's most important crops. A major expenditure of energy is required for curing tobacco (Winfield and Kloster 1976). A reasonable estimate is that about 65-70% of current energy consumption by Ontario agriculture is used in on-farm crop production and preservation.

Lack of time permits an in-depth look at the various details of energy utilization in crop production on Ontario farms. However, the remainder of this presentation will be used to provide a brief discussion in three areas: attitudes towards energy efficiency in crop production, opportunities to reduce energy inputs, and prospects for producing energy from crops.

Attitudes Toward Energy Efficiency in Agriculture

Although minimization in energy usage is a national and provincial goal, to the Ontario farmer, this objective is only important to the degree that it coincides with a larger purpose – the maximization of net income. Over the past decade, much advice has been given to farmers on means of reducing energy inputs, yet the advisors have often been dismayed at the lack of response. The reason has usually been that the changes suggested would mean little or no improvement in net income; in an era when financial survival is the principal concern of most Ontario farmers, the latter consideration reigns supreme. As energy costs continue to climb relative to farm commodity prices, an increasing number of opportunities will arise for farmers to increase net income while reducing energy inputs – a number of these are discussed below – but energy-efficient technology which has no direct effect on standard of living or debt reduction can be expected to be adopted only marginally.

In a similar vein, it should be noted that energy self-sufficiency is also a non-objective to most farmers unless it affects net income or exposure to risk. The latter point is worthy of expansion: in the highly volatile world of farming, most farm businessmen have evolved unusual skills and instincts towards the reduction of risk. This attitude will encourage many farmers to attempt to minimize the risks of energy price variations or supply shortages by "producing their own" even when the effect on average net income might be small. However, most farmers recognize that the viability of modern agriculture depends upon continual interchanges among them, suppliers, and consumers; a return to subsistence-type, self-contained farming is unrealistic and impractical relative to both their own personal goals and ratios. Much has been made by numerous authors over the past decade of the fact that energy output-to-input ratios of modern agriculture lie well below those of its primitive equivalent. Although these analyses have provided an interesting perspective, they are over-shadowed by three larger considerations, i.e., the facts that (1) a Joule of energy in the form of food is far more valuable to mankind than a Joule in the form of petroleum or electricity, (2) primitive-style agriculture cannot feed a world population of 4-plus billion people, and (3) primitive-type agriculture produces low farm net incomes. As a consequence, computations of energy efficiency ratios are largely irrelevant. It is of interest to note, however, that crop production represents one of the few activities of man where renewable, combustible energy is created (in this case, via photosynthesis).

Opportunities to Reduce Energy Inputs

The three major energy input costs involved in crop production, in addition to transport and equipment manufacturing costs which are beyond the scope of this presentation, entail the manufacture of nitrogen fertilizer, fuel for field operations, and energy for drying and curing. Good opportunites exist to reduce all three.

Most of the nitrogen fertilizer applied in Ontario is used for the production of corn and other cereals. Great enthusiasm existed during the 1970's regarding the prospect for reducing N fertilizer inputs for cereals through an enhancement of the activity of N-fixing rhizosphere microorganisms (i.e., microorganisms growing in close symbiotic association with plant roots, which provide the plant with nitrogen compounds in exchange for carbohydrates produced by the plant via photosynthesis). Although research continues on this possibility, and crop biologists remain convinced that symbiotic nitrogen fixation by grasses is theoretically possible (such as routinely occurs with legumes and many other plant species), it now appears certain that this achievement will not occur rapidly or easily.

In the forseeable future, reductions in N input costs on Ontario farms are more likely to be obtained in other ways including: (1) the increased use of crop rotations in which forage legumes are an important component of the crop sequence; (2) the development and use of techniques for delaying or spacing-out-over-time the spring application of N applications to corn, thereby reducing the likelihood of leaching or denitrification losses caused by heavy rainfall in late spring; (3) the expanded use of nitrification inhibitors which retard the transformation of ammonium to nitrate by soil bacteria, and thus reduce the risk of nitrate-N loss by leaching, and (4) more efficient use of the nitrogen-supplying potential of manure.

It's quite reasonable to expect that the N input on Ontario farms could be more than halved through the use of these practices. However the extent to which this is achieved will depend on results of future research needed to "fine tune" these techniques, and changes in the ratio between crop commodity prices and per-unit N costs. From a provincial or national perspective, it is worth noting that the principal saving in energy achieved through reductions in N fertilizer use will involve cutbacks in the consumption of natural gas, and natural gas is expected to be available in abundant supply from Canadian sources for many years to come. Reductions in use of nitrogen fertilizer are important to farm net income, but not necessarily for the Ontario or Canadian economy.

Fuel for field operations is more crucial since this involves petroleum products for which the crude Canadian supply is small and dwindling. The largest opportunity to reduce the fuel cost for field work involves tillage; prospects for reducing field travel for planting, application of fertilizer and chemicals, and harvesting are much smaller. A good amount of research is underway in Ontario on methods of reducing tillage energy input costs while maintaining or augmenting net farm income, and it is anticipated that this research will intensify. Results of the research are being extended to and exploited by Ontario farmers. Net income can be increased and fuel usage decreased by the adoption of reduced tillage techniques although the specifics of these reductions are highly dependent upon crop, previous cropping history, and soil texture. Year-to-year differences in weather also have a large bearing on relative crop responses to tillage; however, because most of these differences cannot be predicted in advance, they cannot be used in more than a general sense in recommendations for the use of minimum-tillage methods, even though they do have a major effect on farmer reaction to, and acceptance of, new cultivation technology.

Although zero tillage (i.e., no tillage, slot tillage, or direct drilling, depending on local terminology) has proven popular in many areas of North America, this technique is unlikely to prove to be widely popular in Ontario. Although there is an obvious saving in fuel, this is usually counterbalanced by other problems including lower yields, higher management requirements, and increased costs for pesticides and N fertilizer. Of course, this situation could change if farmers received direct public compensation for using zero-till seeding methods as now occurs commonly in many parts of the United States.

The third area of potential for reducing the energy input for crop production involves crop drying and curing. In this realm, major gains have already been achieved. Energy-efficient dryers which cause air to be exhausted at a lower temperature and higher relative humidity, or which cause low-relative-humidity exhaust air to be recirculated through the dryer are now widely used by farmers, with resultant improvement in energy efficiency and net income. Farmers are learning how to store grain at higher moisture percentages, and to transfer grain hot from artificial dryers into storage bins where it can be cooled slowly by ventilation, thereby using the sensible heat released to achieve further drying – and both have meant significant savings. At the same time, technology is being perfected to use crop residues as a fuel source for crop dryers, and to recover more of the sensible heat plus part of the latent energy lost in drying through heat pumps. However the capital for these refinements is large, and their wide-spread adoption by Ontario farmers cannot be expected until the financial incentive for change becomes greater.

The prospect for notable savings through the use of solar energy in crop drying and curing seems minimal; capitalization costs for collectors are likely to remain too expensive when compared to their potential to supply heat during the relatively short periods of grain drying in autumn.

As fuel costs continue to grow, expansion in the use of corn cribs can be expected, coupled with innovations in techniques for automating their loading and unloading. However, it is unreasonable to expect a marked return in Ontario to the pre-combine era when cribs were the dominant means of storing cash-crop corn. Although major improvements are possible in the labour requirements and the capacity-limitations associated with traditional crib storage, the management problems will remain (i.e., the problems of avoiding in-crib spoilage, excessive losses during ear harvesting and storage, and excessive drying of grain in late spring and summer).

Some increase in storage of grains as high-moisture grain silage can be expected although the potential for expansion is not large. The major growth in grain production in Ontario during the 1980's will involve production for export markets rather than for home-grown livestock feed, and high-moisture storage is not suited for the former because of quality considerations. It should be noted that a notable energy inefficiency in Ontario agriculture concerns the current practice of drying grain destined for poultry feed, but obvious solutions to this problem are not apparent.

Opportunities to Produce Fuel Energy from Crops

The subject of plant biomass, and its potential as a fuel energy source, is covered by N.C. Stoskopf in another paper in this conference. As a consequence, my discussion will be limited to a few brief comments.

The first of these involves a reaction to the oft-repeated misconception that Canada or Ontario cannot afford to devote agricultural land to energy production since all of this land will be required in the imminent future to produce food. The reality is that Canada, like the United States and many other developed western countries, has a far greater ability to produce food than to consume it. Even when export opportunities are considered, the likelihood is that agricultural surpluses rather than food shortages will continue to characterize Ontario agriculture for many years to come (more elaboration on this point is provided by Daynard 1982). Thousands of hectares of crop land in Ontario could be devoted to energy production with no notable effect on food supply or prices, both today and in the forseeable future. The extent to which this happens will depend upon technology, Canadian oil prices, and potential effects on farm net income.

The most likely and immeidate way in which crops will be used as fuel energy will be through the use of crop residues as on-farm fuel. Techniques are already being used in Europe, and, to a lesser degree in North America, for burning cereal straw, corn cobs, and other on-farm cellulose-hemicellulose-lignin materials, in crop dryers and for the heating of buildings. As energy costs continue to grow, relative to other costs and prices, and as the technology continues to improve (i.e., becomes less expensive and more automated), we can expect an expanded use of crop residues as a fuel source on Ontario farms.

A second means of using crop products in the near-term involves expansion in the production of fuel alcohol from grains. Although initial euphoria over the use of pure ethanol or ethanol-water mixtures as fuel has passed, there are clear signals from the United States that the production and consumption of gasoline-ethanol mixtures containing 3 to 10% ethanol will grow markedly in the decade ahead. One source (AGPM 1982) has listed a prediction that U.S. corn consumption for ethanol production will increase from 1.4 million tonnes of grain corn equivalent in 1981 to 15.4 million tonnes by 1985. Although ethanol will likely remain more expensive to produce per litre of product or per Joule of gross energy than gasoline, this disadvantage those of Canadian society.

A final comment involves energy "efficiency" will be more than off-set by the octane-enhancing and knock-inhibiting properties exhibited by the blend. Technology is also improving rapidly in this area. Present inefficiencies in ethanol production (i.e., high energy inputs for distilling, etc.) can be expected to be corrected in the near future. Although the Canadian situation will lag behind that of the United States (the size of the grain surplus is not so large here and the federal government is less committed to fuel alcohol production), we can doubtlessly expect an increase in grain use for fuel alcohol production in this country as well. Note that this growth should be expected in the realm of commercially produced fuels; on-farm fuel alcohol production is likely to remain in the hands of hobbyists.

A more distant prospect involves production of biomass field crops for fuel, i.e., via the concept that carefully located "biomass conversion" plants will collect biomass from neighbouring farms and convert this into commercially marketed or cooperatively distributed fuels. Acceptable on-farm technology already exists for this process – i.e., present techniques for harvesting, storing, and transporting forage crops as hay or silage could be used readily for biomass production – although further investigation is needed on methods for maximizing crop biomass yields, for reducing the cost per unit of delivered product, and for minimizing the impact on soil erosion. Further research is also needed on methods for converting biomass to fuel, although the process of pyrolytic conversion looks attractive (Tollenaar et al. 1982). Methanol production is also an alternative. At the moment, commercial programs for producing, harvesting, delivering, and converting crop biomass into liquid fuels via procedures sketched above are far from economically feasible. However, as fuel costs continue to rise, this situation could change. A key question will be whether the financial incentive inherent in higher fuel prices is likely to be obliterated by corresponding increases in production and transport costs for the raw biomass material.

The final prospect involves on-farm production and crushing of vegetable oil crops to produce a substitute for diesel fuel. At the moment, this looks appealing because of the simplicity of the processing procedure. However unanswered questions remain as to long-term effects of on-farm-produced vegetable oils on diesel-engine performance. Acceptance by farmers will also depend on the extent to which they can use the byproducts as an animal feed.

Summary

The preceding discussion can be summarized in a few sentences. Although only 3% of current Ontario consumption of energy occurs in primary agricultural production, this expenditure represents a major drain on the financial resources of provincial farmers. Hence, the incentive to reduce energy input costs is large. Good opportunities exist to reduce these costs in the areas of nitrogen fertilizer usage, field tillage, and crop drying and preservation. Opportunties will increase for using crops as fuel energy and will include the burning of crop residues as fuel, the off-farm production of ethanol, the harvest of biomass crops to produce pyrolytic oils of methanol, and on-farm extraction of vegetable oil crops.

References

1 Association Générale des Producteurs de Maïs, "Aux U.S.A., alcools et sucres"; **AGPM Information**, 116: 2, Dec. 1982.

2 Daynard, T. B., "Brief to committee reviewing federal feed grain policy" **Unpubl. manuscript**, Sept. 1982.

3 Ontario Energy and Agriculture Policy Committee, Energy and Agriculture, Vol. 1, Summary and recommendations. **Ont. Government Bookstore, Toronto**, Sept. 1981, 50 pp.

4 Ontario Ministry of Agriculture and Food, **Agricultural Statistics for Ontario**, Publ. 20, Aug., 1982.

5 Pinnington, P. E., "The Canadian energy situation and its implications to Ontario agriculture", Notes on Agriculture, **University of Guelph** 12 (4): 3-6, Oct., 1976.

6 Tollenaar, M., Bookcock, D., and Daynard, T. B., "Production and liquefaction of agricultural biomass", Proceedings, Fourth Bioenergy R and D Seminar, Winnipeg, **National Research Council**, 1982, 297-298.

7 Winfield, R. G., and Kloster, G., Energy for Tobacco Curing in Ontario, **Ont. Min. Agric. Food and Ont. Min. Energy, Toronto**, March 1976, 29 pp.

Energy Considerations in Livestock Production

by:
W. D. Morrison
Professor, Department of Animal and Poultry Science
Ontario Agricultural College
University of Guelph
Guelph, Ontario

Abstract

Conservation of energy is important for both long-term and short-term reasons. Animals are not produced to provide energy for humans, but as sources of protein, minerals and vitamins. As society has prospered, the use of animal products as a proportion of the human dietary, has increased. Energy enters the animal as food and leaves it as heat, manure or product. Only a relatively small amount of metabolized energy is in the product (meat, milk, eggs) with the majority of energy leaving the animal as heat. Means whereby heat loss from the animal can be minimized are discussed. Manure is also a major form by which energy leaves the animal. Proper storage and handling of manure can mean large savings in energy.

Introduction

The reasons for conserving energy in animal production can be reduced to two. First is the economic factor, which is really short-term. The second is the need to conserve a resource over a long-term and the latter does not necessarily support the former. It isn't difficult to convince a producer that certain conservation steps should be taken if the returns can be seen. It is more difficult and perhaps unfair to ask the same producer to take steps for which returns cannot be seen but which may reduce total energy use. This dilemma is seen in many aspects of agriculture and, indeed, throughout society. Individual citizens often do not take kindly to measures designed to help the society of the future but paid for by the society of today.

It is clear that animals are not fed primarily as a means of providing energy for humans. Figures provided by Mowat[1] demonstrated how very little of the gross energy consumed by food producing animals is returned in a form suitable for humans (Table 1). Animals are not produced as energy sources, but as protein, vitamin and mineral sources, and because people enjoy eating animal products.

It is common knowledge that animal agriculture has developed in its most advanced state only as personal income has grown. Blaxter[2] has pointed out that animal production is closely related to crop production and that new developments in primary food production result in opportunities for animal increases. He emphasizes that while total land under cultivation is still increasing, the quality of much of this land is decreasing. Hence the increased production of food, needed by the world's population, must come, more and more, from increased yields on existing land. This means, among many other things, that animal manure must be wisely and carefully used to maximize productivity at the primary level. It also means that the efficient use of feedstuffs for animal production must be maximized. It is beyond the scope of this paper to enter into the moral aspects of feed for animals. It is taken as a given that such will continue and that for moral and economic reasons efficient use of feed and all energy sources is a requirement.

Energy Conservation

What steps can the producer logically take to efficiently use and conserve energy? This paper will deal with procedures involved in actual animal production and only refer in a cursory way to aspects involving crop production. Clearly the two are closely related, but crops are dealt with elsewhere.

Before looking at areas of possible improvement it is necessary to review the source and destination of energy in animal production. A hog finishing barn will be used as an example.

Energy entering the barn does so from three main sources, feed, electricity and fossil fuel. Depending on the type of barn, direct solar energy may also be of some importance. Energy leaves the barn as product, heat and manure. Very clearly it is to the producers' advantage to maximize the amount of product and reduce, by all reasonable means, that lost by heat. An examination of some factors involved follows.

An animal loses heat by four paths, conduction, convection, radiation and evaporation. As environmental temperature increases evaporation becomes most important, as environmental temperature decreases, radiation and convection are the major means of heat loss. An animal housed in a pen with cold walls, radiates heat to those walls. If in addition there is a draft in the pen, still more heat is lost. Thus rather than using food energy for product, it uses it to maintain body temperature and gain or egg production or milk production decreases. A simple conservation procedure then is to surround animals with insulated walls and ceilings and pay attention to unwarranted air movement.

Energy in feed may be measured by calories. Gross or total combustible energy is only obtained when the feed is completely burned. The animal body cannot do this, so something less than all the energy is available to the animal.

When feed is eaten some of it is not digested and passes through the tract and is voided in the feces. In non-ruminants about 80-85% of the total energy is digested. Of that digested, some is lost as gas and some as urine leaving about 90% as metabolizable energy. Unfortunately the remaining energy cannot all be used for product. Some is used to maintain the animal's life processes and in so doing some is used for heat. That which is available for product is further reduced by heat produced in the process of making product – meat, milk, eggs. Thus the total energy in the product produced may be 20-30% of total energy consumed as feed. This very substantial loss occurs even when the animal is housed in a comfortable environment. That which occurs in colder environments will be looked at later.

The second source of energy is electricity or fossil fuel. Southwell[3] has calculated the energy in a finishing barn provided by electricity to provide light, water, ventilation and so on and this figure is used below.

What are the totals for energy for 200 hogs housed in a finishing barn for 100 days? Assuming a feed intake of 500 lbs per pig, total energy consumption will be about 186,000,000 kcal. 52,000,000 kcal will be in the manure, 40,000,000 kcal will be in product and the remainder 93,000,000 kcal will have left the building as heat.

Electrical energy entering the barn will have amounted to 3,225,600 kcal. Thus feed energy leaving the building as heat is about 30 times the amount of electrical energy used! While some energy can be saved and should be saved by careful use of electricity, only a small saving (3%) in feed heat loss could equal the total electrical energy used in this example.

The second major energy loss is in the manure. About 15-20% of the energy consumed moves directly through the animal. How can this be reduced? One method is to feed more digestable ingredients but this is impractical since a producer feeds that which is most economic. A second method is to use the manure in a manner which maximizes energy use.

The major use for manure is as fertilizer. This is extremely important and relates to the point made earlier concerning soil fertility and maintenance. Improperly handled manure compared to manure properly handled can mean an increased loss of nitrogen of 55%.[3] The figure for phosphorus is 65%.

Putting this into another example, the loss of 40% of the nitrogen per year from a 100-cow operation is equivalent to wasting 3,000 gallons of gasoline per year, not an insignificant figure.

Thus it is seen that energy loss in animal production is primarily as heat and manure. What further can be said of these factors?

Heat

In the example used, finishing pigs, no supplemental heat is needed. The animals produce so much heat that a satisfactory environmental temperature can usually be maintained. What about young animals, whose heat requirement is not met by heat produced in the body? Obviously heat must be added and this is most often done by fossil fuel. Here the producer is quite aware of heat loss because it is an economic reality measured in the bill received from the supplier. Despite this, evidence indicates a great variation from producer to producer exists.[3] Table 2 taken from Southwell shows just how great the differences are in this sample between the most efficient and least efficient broiler houses in terms of energy consumption per broiler produced. Variation of this magnitude shows clearly that huge savings are possible with proper ventilation, insulation and critical management.

How significant is a change of a few degrees in temperature in productivity and thus energy loss?

Curtis[4] has calculated that a full-fed pig weighing 130 pounds requires an extra .036 pounds of feed for each degree below 55°F. Thus if the barn temperature is 45°F. it would require an extra 0.36 pounds per day per pig just to maintain body temperature.

It has been shown in chicks[5] that going from a hot to a cool environment could reduce the proportion of metabolizable energy going to product (gain) by 38%. Extreme conditions can cause no gain in energy by the animal, thus zero utilization of energy for production.

Of course temperature is only one factor in the heat-loss equation. The rate of air movement over the pig, the type of floor and the insulation value of walls and ceiling all are very important factors. Assuming an air speed over the pig of 1.5 feet/second, 13°F must be substracted from the air temperature to estimate effective environmental temperature.[4]

If slotted concrete is used as flooring an additional subtraction of 10°F is needed. Finally, the effect of the cool surfaces of wall and ceiling must be considered as an area to which heat can radiate from the animal. If the temperature inside is 70°F and outside is 0°F and the R-value is 2, then an additional 13°F must be subtracted.

Thus, rather than an effective temperature of 70°F the pig, in this case, is really living in an effective environmental temperature of 70°F – 13 – 10 – 13 = 34°F.

What are some of the steps which can be taken to reduce energy loss as heat whether directly from fossil fuel or from feed?

1 Insulate the building to an acceptable standard. Heat loss is related to the effectiveness of material to resist heat flow and this resistance is measured in R-values. Heat loss in BTU/hr/F° can readily be calculated if the R-value and area are known. If the finishing barn in the example had ceiling dimensions of 24 x 60 feet and an R-value of 24, the heat loss potential would be 1440 ÷ 24 = 60 BTU/hr/F°. Assuming 8" walls, with an R-value of 2, the heat loss potential would be 1344 (wall area) ÷ 2 = 672 BTU/hr/F° from the walls. it is important to remember that perimeter insulation is also necessary to reduce loss of heat. If perimeter insulation is increased to an R-value of 12, heat loss through the perimeter is reduced from 136 BTU/hr/F° to 28 BTU/hr/F°. If the R-value in the walls was increased to 12, the heat loss potential of the walls drops to 112 BTU/hr/F°. Thus, by improving insulation total heat loss potential is reduced from 868 BTU/hr/F° to 200 BTU/hr/F°.

   Pursuing this further, if the assumption is made that the temperature inside the building is 60°F and the outside temperature 0°F the total daily heat loss through the walls, ceiling and perimeter can be calculated.

   When the wall and perimeter are poorly insulated heat loss per day is, 868 (BTU/hr) x 24 (day) x 60 (temperature difference) = 1,249,920 BTU or 315,000 kcal which equals 34% of total heat loss. On the other hand when insulation is increased heat loss per day is 200 x 24 x 60 = 288,000 BTU or 72,544 kcal which only totals 8% of heat loss.

2 Reduce factors which tend to require the use of either fuel or feed to maintain animal comfort. Ventilation control is vital in this regard. In cold weather, air must be warmed to increase the moisture holding capacity. The energy required to heat the air is determined by multiplying a constant (1.1) x the ventilation rate (cfm) x the difference between the inside and outside temperatures (F°). In cold weather, with proper insulation, heat loss by ventilation is by far the major portion and minimum ventilation rates[6] may need to be followed closely. An example of such rates is given in Table 3.

   All equipment must be kept clean including fans, louvres, thermostats, and ventilation tubes.

   Balancing air inlet capacity with exhaust capacity will minimize drafts. Slight negative pressure allows incoming air to mix with inside air rather than falling on the animals.

3 Maintain sufficient animals in a given area so there is a reasonable balance between heat produced and heat required to maintain adequate temperature where feasible. The balance between feed and fuel to maintain environmental temperature can be calculated and should be considered. As pointed out earlier for every F° below the lower critical temperature of a pig weighing 130 pounds on full feed an additional 0.036 pounds of feed is required daily to maintain body temperature. For illustrative purposes, assume the effective environmental temperature of the finishing barn is 10F° below lower critical temperature. With 200 pigs in the barn the extra feed will be 0.036 x 200 x 10 = 72 pounds per day.

   Rather than feeding extra feed, the environmental temperature could be raised by fossil fuel or electricity. Recall that heat loss through ceiling, wall and perimeter and by ventilation is related to the difference between the inside and outside temperature. In this case the inside temperature must be raised 10F° thus the difference between inside and outside air will be increased by 10F°. Increased loss through the ceiling will be 24 x 60 x 10 x 24 ÷ 24 = 14,400 BTU/day or 3,629 kcal. Wall loss will be increased by 168 x 8 x 10 x 24 ÷ 12 = 26,800 BTU/day or 6,770 kcal. Perimeter loss will be increased by 168 x 2 x 10 x 24 ÷ 12 = 6720 BTU/day or 1693 kcal. Thus increased heat loss through ceiling, walls and perimeter is 12,092 kcal per day.

   Increased loss through ventilation will be based on increased temperature difference (10F°) the cfm and a factor, (1.1). In this case, assuming a ventilation rate of 2 cfm per pig the increased heat loss is 1.1 x 200 x 2 x 10 x 24 = 105,600 BTU/day or 26,612 kcal. Thus total extra heat to be added to the building per day will be 12,092 + 26,612 = 38,704 kcal. If this is to be supplied by electrical energy it will require 38,704 ÷ 860 or 45 kwh. If derived from fuel oil, the added loss would equal about one gallon per day. Comparative costs of feed or fuel can now readily be made.

4 Where feasible, house animals in groups, rather than singly so that the natural tendency to conserve heat by being close together can be exercised.

5 In buildings where bedding is used additional straw can help reduce heat loss.

6 Pay attention to proper placement of buildings when new construction is being considered. Placing the building with the long axis oriented east-west allows for maximum solar heating of the wall during winter weather. Eave overhang can be beneficial in summer to provide shade. Windbreaks can help reduce heat loss.

7 Some form of heat exchanger will almost certainly be developed which will be suitable for wide application. Considering the huge amount of heat presently exhausted into the atmosphere, such a development will be a major step in conserving energy in animal production.

8 While the emphasis has been on management in cold weather, energy can also be wasted by poor mangement in hot weather. If animals cannot get rid of body heat in hot weather, feed intake is reduced, a larger proportion of energy consumed then goes for non-productive functions and energy is wasted. Well-insulated, well-ventilated comfortable surroundings are also important in hot weather to make most efficient use of energy.

Loss of Energy in Manure

The availability of NPK in the form of purchased fertilizer has tended to reduce the attention given to conservation and preservation of manure. It is often looked upon as a nuisance instead of an asset. But what are the facts? If consideration is given to the energy required to manufacture fertilizer (NPK) certain very sobering points can be made. For example, the energy value of NPK in the manure produced by a beef steer is about 6 times the nutritional energy value of the carcass.[3]

The 200 hogs in the finishing barn used as an earlier example will produce approximately 300,000 pounds of manure. This will contain 2,000 pounds of nitrogen, 1,200 pounds of P_2O_5 and 800 pounds of K_2O. The energy value of the NPK is about 22,400,000 kcal. This figure, however, is based on the energy required to manufacture equivalent quantities of NPK.

Note what happens to that energy with improper handling (Tables 4 and 5). As much as 80% of the nitrogen and phosphorus can be lost from a lagoon-type storage. In addition, if the manure is not incorporated into the soil in a reasonable time, additional losses occur.

Energy conservation requires proper and careful handling of manure since it contains an important portion of the total energy fed to livestock. The possibility of producing methane from manure while still preserving the NPK is discussed elsewhere as are proper handling procedures. It is mentioned here because of its extreme significance in the total energy picture in animal production.

Feeding Manure and Low-Energy Roughages

Southwell[3] has provided great detail concerning the energy value per acre of what are commonly thought of as low energy roughages, including straw and stover. The energy in an acre of stover is calculated to be 7,400,000 kcal and in an acre of barley straw 3,300,000 kcal. Unfortunately it is not possible to make use of these products for non-ruminant animals and only possible to a limited extent in ruminants. Research is being carried out on a wide front with the aim of releasing a significant amount of that energy for livestock production.

Manure from non-ruminants can be fed to ruminants and thereby retrieve more of the nutrients, including energy. Under our present specialized systems of production, the widespread application of this procedure is most difficult.

In summary, animal producers can best conserve energy by taking all reasonable steps to reduce feed wasteage, heat loss from animals in their care and make the most of the nutrients in manure. As efficient heat exchangers become available these should be incorporated into the system whether using direct solar energy, recapturing some of the heat lost from buildings or a combination of these and other means.

References

1 Mowat, D. N., Summers, J. D., Bowman, G. H., Burton, J. H., and Usborne, W. R., Efficiency of Production of Meat and Milk, Proceedings of the Ontario Institute of Agrologists, Fifteenth Annual Conference, 1974.

2 Blaxter, K., Animal Agriculture in a Global Context. Annual Meeting, American-Canadian Societies of Animal Science, August 1982.

3 Southwell, P. H. and Rothwell, T. M., Energy costs and Output/Input Ratios for Ontario Agriculture. School of Engineering, University of Guelph, 1978.

4 Curtis, S. E., Pig Energetics – the Diet and the Environment. University of Illinois Pork Industry Conference, 1981.

5 Olson, W. D., Sunde, M. L. and Bird, H. R., The Effect of Temperature on Metabolizable Energy Determination and Utilization by the Growing Chick. Poultry Science 51: 1915-1922, 1972.

6 Deshazer, J. A., Shelton, D. P., and Bodman, G. R., Energy Conservation Alternatives in Swine Production, University of Illinois Pork industry Conference, 1981.

Energy Produced in Physiological Fuel Values as Percent of Gross Energy Intake.

Table 1

Product	% of GE Intake
Pork	5
Broiler	10
Eggs	14
Milk	16
Beef	1

Mowat et al, 1974.

Energy Consumption for Heating, per Broiler Produced (BTU)

Table 2

	Natural gas	Fuel oil	Propane	Electricity
Minimum	6,450	9,580	3,440	1,160
Maximum	26,000	19,000	14,440	5,630
Average	14,210	14,700	9,400	3,520

Southwell and Rothwell, 1978.

Winter Continuous Minimum Ventilation Rates for Pigs

Table 3

	CFM/pig
Dry sows	
– group	5.0
– individual	4.0
Sow and litter	
– 3 weeks	15.0
Weanling	
– 15-50 lbs	2.0
Growing	3.0

Confinement Swine Housing, Publication 1451, Agriculture Canada.

Relative Nutrient Losses from Stored Manure

Table 4

Solid	N	P_2O_5	K_2O
Daily scrape, haul	25	5-15	5-15
Manure pack	35	5-15	5-15
Open lot	55	50	40
Deep pit (poultry)	20	5-15	5-15

Southwell and Rothwell, 1978.

Relative Nutrient Losses from Stored Manure

Table 5

Liquid	N	P_2O_5	K_2O
Anaerobic pit	25	5-15	5-15
Oxidation ditch	60	5-15	5-15
Lagoon	80	80	5-15

Southwell and Rothwell, 1978.

Energy Considerations in Greenhouse Production

by:
Ir. W. P. Mulder
Institute of Agricultural Engineering
Wageningen, The Netherlands

Abstract

In the Netherlands, greenhouses are intensively used in the production of vegetables and flowers. The advantages of protected cultivation are: a continuous quality control of the products, a year round production in an outdoor climate which is not suitable, and an economical use of water and fertilizers.

The world wide energy shortage has initiated a great study effort into the matter of reducing the yearly energy costs for the grower. In this paper, results from next study aspects are reported.

Energy demands

Depending on crop, type of heating system (I.R.-heating) and outdoor climate conditions.

Insulation of greenhouses

The use of energy curtains and insulating greenhouse covering. The influence on the micro-climate of the crop and the light reduction which is caused by the insulation.

Alternative energy sources

Possibilities for heat pumps, wind energy and rejected heat from industry and electricity plants, the use of energy storage.

Climate control

Deviation on the temperature setpoint caused by inertness of the heating system.

Crop response

Correlation between energy demand and production, crop response on the greenhouse insulation and on the uses of rejected heat.

Introduction

The Netherlands have a mild sea climate: not too cold in winter and not too hot in summer and just such light conditions that it is possible to have a year round production in greenhouses. In northern regions of Europe the winter light conditions are too poor and in the south the summer outdoor temperatures are too high.

To maintain a suitable indoor climate in winter, heating is necessary and at this moment an average of 50 m^3 gas/m^2 floor area per year is consumed (Net heating value of Dutch natural gas being 31.7 kJ/m^3).

Advantages of greenhouse production are:

- guarantee of good quality in vegetable and flower production;
- restricted amount of water for necessary plant evaporation compared with open field production.

The total heated glasshouse area is about 8,000 ha with an export production of Dfl. 4.10^9 ($1.8 billion Cdn.). The production ratio of flowers/vegetables is 50/50.

As energy prices in Holland have risen tremendously, studies in the field of the protected cultivation are at this moment mainly concerned with reducing the energy costs. The technical studies are focussed on insulation, alternative energy sources, climate control and plant reactions. This paper gives an overall view of the state of the art.

Energy Demands

Whenever the use of greenhouse insulation or alternative energy sources is considered, an estimation of the energy needed to raise a crop should be made before hand.

With observed average outside conditions, the known energy leakage of the glasshouse and an assumed suitable indoor temperature, an average yearly energy demand can be calculated.

In reality, the growers do not follow too well the blueprints for production and they use energy saving techniques so there always is a considerable gap between the calculated amount of needed energy and the observed use of it.

One example: a grower at Naaldwijk is using 15 m^3 gas/m^2 for the growth of carnations, reducing the energy demand by laying heating tubes in the dense canopy and letting the air temperature drop to 10°C. The normal calculated value is 30 m^3/m^2.

Another method we expected to influence the energy demand was the use of infrared heating. However, so far, we have found no notable energy reduction when compared with a greenhouse with low situated heating pipes.

Figures of importance are:

- the year round energy demand duration;
- energy demand in the night;
- energy demand in day time;
- fluctuations in energy demand in a 24 hour period.

Glass House Insulation

A greenhouse is constructed in such a way that a maximum amount of sunlight is admitted while preventing heat going out.

Every use of insulation is aimed to help preventing heat going out but will have effect on light admission. Light, especially in dark winter periods always has a positive effect on growth of plants, while in all studies of insulation light reduction effects are taken into account. The research for insulation possibilities is divided in two main directions:

a The use of movable insulation: energy screens.
b The use of fixed insulation: greenhouse covering materials.

Energy screens are already applied on large scale. From glass different materials for greenhouse covering are taken in study being focussed on the physical properties such as: tensile strength, light and heat transmission and standability against hail.

Both sorts of insulation have their influence on the indoor climate, specifically, the relative humidity, air movement and air temperature patterns.

The results of the study for energy screens are a wide range of useful materials and a reliable screening construction. Technically, it is possible to construct a screen which could reduce the nightly energy demand almost to zero. So far the crop response to such a heavy energy screening is not known. Most plants need a cold period at night and also the reduction of air movement can have effects on the plant growth or the circumstances for diseases. This type of screen is not yet available and, from the above mentioned questions, it still is a question whether such a screen is useful although it can reduce the yearly energy as much as 70%.

The study for greenhouse covering materials is being carried out in cooperation with an insurance company. At this moment most physical properties are known or being measured and testing methods are being described. Also, calculation methods to determine the heat transmittance and construction properties are proposed. When all study details are finished, results will be published and materials can be compared. The aim is to provide a grower with a certain guarantee from the materials he is going to purchase.

Alternative Energy Sources

The Dutch greenhouse industry derives about 80-90% of its heat from natural gas. The gas is very pure and flue gases can be used for CO_2 enrichment. Also, it is possible to cool the flue gases down below condensation point without too much trouble from aggressiveness and a high efficiency (100%) of combustion can be obtained. The modulating control of gas fired burners at this moment has reached a very high level of performance.

When considering the use of alternative sources, the advantage of the existing gas fired boiler is tried to explore and most studies are concerned with energy supply from two sources wherein the gas boiler is to cover the peak loads.

The use of two heat sources has consequences for climate control. To switch over from one source to another influences the alertness of the system. This will result in a greater deviation from temperature setpoints. Crop response to this is not too clear and studies are being carried out.

Considered alternative energy sources are:

- waste heat from electricity plants;
- waste heat from industry;
- ground water sourced heatpumps;
- garbage and coal in fluidised bed combustion;
- wind energy.

So far atomic power is not situated within reaching distance of the greenhouse district.

Climate Control

The function of climate control is for a grower to maintain a selected indoor climate. In one or more places, air temperature and relative humidity is measured, and, when needed, the heating system is switched on or ventilating windows are opened.

Deviation from the selected climate can be due to:

- Functioning of the control system
- Functioning of the heating and ventilating system.

Deviations caused by the control system should not be necessarily of great influence. Especially in the case where computers are used, a high level of performance can be expected.

Short term deviations caused by the heating and ventilating system are most times rule. In particular the next phenomena will be originating troubles:

- existence of big, not controlable, air movements which are causing distinctive cold and

warm spots in the greenhouses;
- inertness of floor heating systems;
- fast changes in the outdoor climate, for example a sudden sunshine.

Improvements can be obtained, but of course that will ask for some new investments. Question is whether these additional investments will result in a higher yield.

Crop Response

As pointed out, there are improvements to the indoor climate that can be made from a technical point of view but crop response is not too well known. Studies are underway to measure the short and long term effects on plants.

The most clear plant reaction to be measured is evaporation, which is clearly seen as visible radiation in daytime, but also occurs at night, driven by the energy brought in by the heating system.

The first result of our experiments was the determination of the amount of water required. It was possible to reduce the water supply to 20% of the original.

Some effects of an energy screen on plant evaporation were found.

As the measuring instrument used is rather heavy and very expensive and only suitable for research, we tried to find another instrument to give an indication of the evaporation level, to be used in practice. The sap flow in the stem of a plant can be measured and, in a certain range, there is a linear correction between this signal and that of the lysimeter.

It is possible to measure to a certain level the temperature of the canopy with rather expensive instruments; when a computer is used the average temperature could also be calculated from air-, roof- and floor temperature.

In another experiment involving the use of artificial light and two layers of crops situated above each other, the yield was 2-3 times better than the original production. In practice, this experiment is carried out with 10 layers of crop situated above each other; the heat from the co-generation to be used for greenhouse heating and a system like this is already to be purchased.

The practical effects of the crop response studies to be expected on short terms are:
- protection of the plant against stress situations (water shortness, too high temperature of the canopy);
- avoiding situations where diseases can occur;
- control strategies with an optimum in energy demand selecting between bringing down relative humidity by heating and opening windows or keeping the relative humidity at high level with minimal heating costs.

The effects on long term to be expected are:
- higher yield with less energy supply without extra investments;
- a possible use of the apparatus for greenhouse environmental control for crop growth control in open air.

At this moment there are many possibilities and questions from technical point of view. Each plant and variety has a different response and though progress will be made a complete controlled plant production is not to be expected.

Conclusions

Greenhouse production in Holland is prospering and energy problems can be overcome.

Guarantee of the production quality can be obtained when growing in greenhouses and improvements can be expected.

In the situation of the world wide shortage of fresh water, protected cultivation could improve food production, as the evaporation rate of plants is only 10% of that in open field production. A rapid growth of protected cultivation can be expected.

Biomass – A Crop Scientist's View

by:
N. C. Stoskopf
Director of Diploma Program and Professor, Department of Crop Science,
Ontario Agricultural College
University of Guelph
Guelph, Ontario

Abstract

Farm-produced organic matter or biomass has value for fuel or lubricant production. Biomass also has value for use as a soil amendment, as a livestock feed, for livestock bedding, for industrial manufacture, as an energy source for single cell bacteria to produce protein, as a source of chemicals, as well as use as human food. Crop biomass cannot be regarded, therefore, as low-value waste. Rather, plant biomass is a valuable resource with the advantage that it is renewable, flexible through crop switching, and adaptable through genetic manipulation.

Fuel production from biomass may involve the grain only; the vegetative plant parts after grain has been removed; both the grain and vegetative portions; by-products from the processing industry; or animal by-products such as manure. Use as an energy source must compete with alternative uses. In addition to economic considerations, however, biomass fuel production must be viewed as a possible means of avoiding the high and rising fossil fuel costs; to counter artificial, real, or threats of fuel shortages; and to serve as a form of insurance that fuel supplies will be available to sustain mechanized agriculture and food production in the future.

Feasibility reports of biomass as an energy source are conflicting in the literature, perhaps because of geographical differences resulting in variations in the amount of dry matter produced, because of enviromental differences affecting the conversion processes or because of variable economic parameters. The Canadian situation involves a short growing season with low light energy and temperature limitations; long, cold winters affecting year-round chemical conversion processes; and a sizeable national fossil fuel supply. Under this situation it is impossible to consider biomass as a major energy source in Canada at least with existing technology.

Biomass restricted to an on-farm fuel use in Canada may be feasible if production is integrated into a total system and this needs to be investigated thoroughly. Such a system may involve livestock production to utilize stillage, and to provide a manure source for both methane and crop production.

Biomass production exclusively for fuel use that further jeopardizes Canada's fragile soils, environment or future food production capacity is unacceptable. A systems approach involving crop rotation with nitrogen-fixing legumes, winter cover crops, and opportunity to maintain soil organic matter, thereby reducing soil erosion and compaction, needs examination.

Research towards fuel production as an integral component of a system is recommended. On-farm adaptation of fuel production from biomass can be adopted in Canada only after users and extension workers have and understand the total package.

Introduction

During the Carboniferous period about 300 million years ago, radiant energy from the sun was trapped through photosynthesis and converted to chemical energy. The products of photosynthesis were transformed to coal, oil and natural gas by geologic action under anaerobic conditions, pressure and heat. Total world supplies of fossil fuels are finite but believed to be adequate for centuries. The problem is that worldwide, as well as in Canada, fossil fuels are unevenly distributed, not in the form desired, and since 1972, artificial price manipulation has resulted in high prices and temporary shortages. Concern about the viability of mechanized food production is fundamental to interest in biomass as a fuel source. Feasibility studies for biomass are, however, conflicting (Glaser, 1975). A renewable, farm-produced fuel source would help avoid high and rising fossil fuel prices, would counter the threat of fuel shortages, and would serve as assurance for continued food production.

Renewable energy from biomass produced through photosynthesis in crop production has an enormous appeal to agriculturists. Not only does it offer energy independence but, it focuses on the very essence of crop production which is to capture and convert sunlight energy to chemical energy. Biomass energy production provides an alternative to surpluses; it provides an incentive to greater photosynthetic efficiency through avenues such as biotechnology; it provides crop production with a new thrust and direction; and all this without exaggerating the overproduction problems of Canada.

The term biomass includes all organic matter, as currently growing material as well as stored residues of plants and animals. In Canada and worldwide, cereals, including corn and sorghum, are by far the most extensively grown of all crops. Cereals produce about equal portions of grain and straw or stover. Small-grain crop biomass, has for many years been bound into sheaves with a binder harvester, gathered to a central point, and greatly valued for a number of purposes. Changes in machinery in recent decades, means that enormous quantities of straw are dropped behind the combine harvester. An accompanying switch to grain corn, especially in Ontario means that residues produced are coarse and difficult to collect because of late harvest and adverse weather. A change in on-farm handling systems that reduced or eliminated the need for bedding, resulted in much straw and stover residues left unused. Often straw and stover residues came to be regarded as waste material and a nuisance. A widespread unease developed about this apparent wastage because of increasing energy costs, potential fuel shortages, and conservation of resources much in the public mind. Often straw is burned in the field to facilitate seeding of a second crop or to eliminate uneven drying and fertility conditions. To avoid environmental pollution and to use biomass residues, the idea of fuel production was stimulated by the action of OPEC. Producers, industrialists and research workers all became interested.

The use of biomass as an alternative energy source has received worldwide attention but reports are conflicting or incomplete. In Brazil, most automobiles burn gasohol that contains 20% alcohol (Dormaar, 1982; Hammond, 1977a). The source of Brazilian gasohol is the fermentation of sugar from sugarcane (Hammond, 1977b), and is reported to cost about $65 to produce a barrel of ethanol compared with about $35 for a barrel of oil purchased in the world market (Pimentel, 1982). In North America, plans are underway to produce gasohol from various biomass sources, including crop wastes but economic feasibility and technical details need to be refined.

A major question is the volume of crop residues to be returned to the soil to maintain crop productivity. Organic residues have value in controlling erosion, maintaining or improving soil structure, and are valuable for the carbon dioxide they release, properties which commercial fertilizers lack. Crop residues, however, are incomplete fertilizers and cannot provide enough nitrogen, phosphorus or potassium to meet the need of agriculture. The bulk of organic agriculture residues in Canada are in the form of animal manures and straw, three-fourths of which are already being used on the land. Other residues including sewage sludge, food processing wastes and industrial and municipal refuse, usually are not utilized on soil because of physical properties and chemical contamination, or because of high costs of handling or further processing.

Productive soils are a vital national asset and attention must be directed first to maintaining this valuable resource. After the soil needs are met, then biomass must be evaluated for use as feed or food, source for industrial manufacture (paper, wallboard), for protein production (using single cell bacteria), in the manufacture of chemicals (Lipinsky, 1981), or for fuel production. Animal and human wastes should be recognized also as biomass since they are products of metabolism in the same manner as are by-products of the feed industry that involve fermentation. Dried poultry waste biomass should not be overlooked as a feed ingredient (Biely, Kitts & Bulley, 1980).

Primary biomass resources include wood, lignocellulosic crop materials or the vegetative portion of crops, and the high energy grain and sugar components of crops. A great deal has been written about energy from biomass, and because the interest has developed faster than the technology, information is somewhat conflicting. The conclusion frequently reached, is that new and renewable options such as biomass for fuel must be developed, at least in developing countries and fuel deficient areas (Dunkerley and Ramsay, 1982).

The responsibility that Canada must assume in researching biomass technology must be considered in terms of Canadian needs as well as for developing countries. I believe Canada should assume a leadership role and suggest that research in this area must be supported.

Sunlight Energy Availability and Conversion

The amount of energy emitted from the sun is enormous. In favored areas of the world the value was reviewed by Hare (1973) and is about 1400 Watts/m^2/year with about 1000 Watts/m^2, reaching the ground under clear conditions. In Canada, the sun's rays are less direct and a low sun increases the path of rays through the atmosphere thereby reducing the intensity. On an average day in Canada in June and July, energy at the ground level falls between 250 and 300 Watts/m^2, about 40% of that received in Arizona or the Sahara Desert. Canada's average solar energy income per year varies from about 85 Watts/m^2 in the Arctic to about 175 Watts/m^2 in the most favored southern areas. Consider further that Canada's land mass does not retain all this energy as heat. After reflection and radiation losses, the net rate of heating varies from near zero in northern Ellesmere Island to about 55 Watts/m^2 in favored areas. Biomass production is dependent on suitable temperature and moisture conditions for plant growth. Conditions suitable for biomass production are limited to a narrow southern zone and then for only during a 100 day growing season.

During this growing period, a great deal of the sun's energy is used to transfer water from the soil to the air through the process of transpiration. The overall efficiency of photosynthesis is less than 1% of sunlight energy in the visible spectrum during the short growing season. Additional cultural energy inputs are required for land preparation, plant nutrients, seeding, harvesting, pest control, drying and handling. Currently in the United States, 41% more fossil fuel is burned each year than the total solar energy fixed by all the plant biomass, including all that is associated with agriculture and forestry (Pimentel, 1982).

Input-Output Relationship in Crop Production

When all inputs into crop production are expressed in energy units, an energy input-output ratio can be determined. Generally, crop production in Canada has a positive input-output ratio of 1:2 to 4, i.e., for each unit of energy expended on crop production to the farm gate, 2 to 4 units of energy are produced. More specifically, a 5600 kg/ha (90 bu/ac) crop of corn in Ontario had a ratio of 1:4.4 (Stoskopf, 1981) when grain alone was considered. Corn is recognized as a high-yielding, full-season, photosynthetically efficient crop because of its C_4 photosynthetic mechanism. On four prairie farms, including irrigated crops at Taber, Manitoba and a dryland wheat-fallow system at Swift Current, Saskatchewan, the average efficiency with C_3 grain crops when grain alone was considered was 2.66 (Timbers and Jensen, 1978).

These disturbingly low efficiency values leave little room for a net gain in energy production from grain. A report from the Pacific Northwest suggests that with existing technology, alcohol production from grain corn nets less than one Joule for each Joule of input (Bettis *et al*, 1982).

Further complicating the input-output relationship is the fact that additional energy is often required to collect and haul biomass residues. North American agriculture is highly mechanized (Rasmussen, 1982) and the means of collection exists, but the question of cost arises.

Fuel from Lignocellulosic and High Energy Biomass

The vegetative portion of lignocellulosic material of crop plant biomass could be used as a fuel by 1) direct combustion, 2) by conversion to more concentrated forms of ethanol or methanol, or 3) anaerobic digestion into methane (CH_4). Methane is the main constituent in natural gas and has a high fuel value in a pure form. Farm production of methane may require scrubbers to remove impurities such as carbon dioxide and hydrogen sulphide that lower its fuel value.

The possibility of combining the grain with the vegetative portion of the crop to produce fuel is a very real possibility. One tonne of grain (2205 lb) could produce 382 litres (84 gallons) of alcohol and an equal weight of lignocellulose (straw) could produce a comparable amount (Hodgson, 1982). The 5600 kg/ha grain corn crop (90 bu/ac) along with the stover could produce over 1364 litres (300 gallons) of ethanol. Depending on the price relationship between grain and fossil fuels, such a system may be viable economically. Both commodities will vary in price but perhaps, just as the 1970s saw the end of cheap fuel, the 1980s may be the end of cheap grain (Anonymous, 1982). More efficient fermentation of grain carbohydrate to alcohol would help assure a place for use of grain biomass.

A fuel from direct extraction of vegetable oil from soybean, canola or rapeseed may be a possibility. Oil extracted from these crops contains 94 to 95% of the energy content of diesel fuel but is 11.1 to 17.6 times more viscous (Bettis *et al*, 1982). Vegetable oils could be used for fuel provided an additive to inhibit carbon and gum formation could be found.

Systems Approach Needed

Input-output energy relationships suggest that biomass production exclusively for fuel production is not economically feasible. A possible solution to this problem is to integrate biomass fuel production into a systems approach whereby the by-product from one enterprise can offset the cost of another enterprise. A system involving livestock and crop production may offer a viable approach because biomass residues can complement livestock production. Fermented biomass called stillage, or unfermented "slop" plus the microbial cell mass accumulated during fermentation is an excellent high-protein feed supplement for ruminants. As well, straw could be chemically treated to increase its digestibility for use as low energy maintenance feed. The resulting manure could be used to produce methane gas (CH_4) for on-farm use such as crop drying (Otten, 1981). Removal of methane reduces the volume by 5 to 7%, does not reduce the nutrient value and produces an environmentally more acceptable product.

Forages associated with a livestock system, are an asset as they allow for a rotational cropping system along with corn or other energy producing crops. Forage legumes convert inert atmospheric nitrogen into a biologically useable form to reduce energy-dependent nitrogen fertilizer needs compared to monoculture corn production. Legume production is inducive to sustaining soil productivity and is environmentally acceptable. Biomass production that encourages such an integrated system may be preferable to intensive feedlot or intensive, monoculture cropping systems.

Biomass energy production in an integrated farming system may take farmers toward fuel independence. The success of on-farm fuel production is dependent on reliable, low cost automatic and efficient on-farm stills and digesters. Large-scale, centrally-located plants, however, may be easier to police against illicit alcohol production and may offer economies of scale. These observations led Hodgson (1982) to conclude that widespread on-farm production is unlikely but perhaps a system of custom work may be developed.

Moving fermentation off the farm may lead to a belief that energy from biomass is a major fuel source but at best only a portion of on-farm needs can be met. The United States, for example, consumes 1½ times more fossil fuel energy annually than the total solar energy captured by all the crops in agriculture (Pimentel, 1981). Clearly, biomass production is a minor resource.

Soil Productivity Considerations

The shift to intensive and specialized cropping systems since World War II has led to widespread concern about soil degradation and future productivity. Intensive cropping systems often result in nearly complete removal of all above-ground biomass with a minimum return of crop residues to facilitate cultivation, to eliminate excessive trash, or for use elsewhere. Specialization may lead to monoculture production of annual crops that provide no winter cover for soil protection. Problems associated with such cropping systems include erosion, soil compaction, a build-up of pests, a shift in important pest species, resistance to pesticides, decline in organic matter, reduced natural fertility, and an overall reduction in productivity. The long-term effects of intensive and specialized cropping systems are only starting to be realized (Rennie, 1979). The United States considers the major current and anticipated constraints for crop production listed in order of priority (Geissbuhler, Brenneisen and Fischer, 1982) to be:

a) soil deterioration by erosion
b) increasingly erratic water supplies
c) rising energy costs
d) progressive contamination of water, air and soil

All four of these impact on crop yields and cost of production, directly or indirectly. There is little surplus land in Canada to produce biomass; agriculture and biomass production compete for the same land.

If a shift to fuel production from biomass results in greater intensification of cropping practices on more farms on marginal land areas subject to erosion, or on fragile or unstable soils, then biomass production must be approached with considerable caution and apprehension. There appears to be little merit in increasing the demands on our land resource base during a period when fossil fuels are still abundant, if it means that soils will be less productive at some future point, perhaps when fossil fuels are less abundant and more expensive. At present, only about 6% of total national energy consumption is used in plant and animal production (Pimentel, 1981). Replacing a part or even all of this 6% energy used in agriculture likely will not have a significant economic impact on the national economy. To provide fuel for one US automobile, using ethanol produced from corn, requires 4.5 hectares of land. In contrast, 0.5 hectares are required to produce food for one person per year (Pimentel, 1982). Nine times as much land area is required to fuel one automobile as to "fuel" one person.

Crop-Biomass Production Considerations

Cropping programs traditionally have been designed to maximize specific aspects such as grain production, protein content, gluten strength, total digestible nutrients, winter survival, loding resistance, a favorable grain-to-straw ratio, the achievement of physiological maturity, moisture content and other specific criteria. These traditional measurements of success in crop production may be less relevant to biomass production. Measures for successful biomass production may be total dry matter production per day and not grain yield, without attention to quality. To achieve the maximum daily productivity, crops may be harvested without regard to stage of maturity if such a timing facilitates multiple cropping. Measurements for the production of canola, rapeseed, crambe or soybeans may be oil content, viscosity, fatty acid composition, energy content or high erucic acid.

Conclusions

A decision to shift to biomass production for fuel extraction can be successful only if economic; environmental and technical aspects are considered and if such information can be presented clearly, accurately and convincingly through extension and information channels. Much of the technical aspects associated with anaerobic digesters, alcohol production, storage and handling has been described (Anonymous, 1980; Hayes, 1981; Higgins, 1981; Pos *et al*, 1981) for Canadian conditions. The economic, and environmental aspects need refinement over an extended time period. Environmental concerns may be alleviated by a systems approach involving on-farm utilization of energy and by-products of the animal and cropping programs but demands on the management of such a system will be heavy.

The use of surplus, conventional food commodities (grain) for fuel production is sure to bring a reaction from moralists. Under conditions of a food shortage somewhere in the world because of poor distribution of food resources, the moral issue will arise and could be a strong deterrent.

Canada's future agricultural energy needs will increase, not decline. As easily obtained, clean-burning and convenient fossil fuels are depleted, the hope is that new energy sources will be developed as rapidly as fossil energy resources disappear. Crop biomass may play a role, although probably minor, in helping meet future energy needs. In working out energy solutions, it must always be kept clear, that energy is valued not for itself, but for the contribution it makes to economic growth, and the satisfaction it generates in providing food, clothing, transportation and warmth for human needs. Biomass can help supply energy, but careful evaluation of all factors relating to biomass must be recognized and considered.

The organizers of Energo '83 are complimented on bringing agriculture's role, opportunity and responsibility in energy use and production to the forefront.

References

1 Anonymous. Farm-Scale Production and Use of Fuel Alcohol. Opportunities and Problems. **Agriculture Canada Publication 1712,** 1980, pp. 1-9.

2 Anonymous. Another 174,000 Joined Us at Breakfast Today. Editorial Comment. **World Crops,** March April 1982, pp. 45-66.

3 Bettis, B. L., C. L. Peterson, D. L. Auld, D. J. Driscoll, and E. D. Peterson. Fuel Characteristics of Vegetable Oil from Oilseed Crops in the Pacific Northwest. **Agronomy Journal** 74:335-339, 1982.

4 Biely, J., W. D. Kitts and N. R. Bulley. Dried Poultry Waste as a Feed Ingredient. **Animal World** No. 34:35-42, 1980.

5 Dormaar, J. F. Humus or Gasohol Production from Crop Wastes. **Canada Agriculture** 27:37-38, 1982.

6 Dunkerley, J. and W. Ramsay. Energy and the Oil-Importing Developing Countries. **Science** 216:590-595, 1982.

7 Geissbuhler, H., P. Brenneisen, and H. P. Fischer. Frontiers in Crop Production: Chemical Research Objectives. **Science** 217:505-510, 1982.

8 Glaser, P. E. The Solar Energy Options – Approaches to Develop New Energy Resources. **Proceedings from the Seminar on Solar Energy,** Massachusetts, 1975, pp. 1-3.

9 Hammond, A. L. Alcohol: A Brazilian Answer to the Energy Crisis. **Science** 195:564-566, 1977a.

10 Hammond, A. L. Energy: Brazil Seeks a Strategy Among Many Options. **Science** 195:566-567, 1977b.

11 Hare, F. K. Energy, Biomass and Environmental Impact. **Proceedings International Biomass Energy Conference,** Winnipeg, Manitoba, pp. II 1-8, 1973.

12 Hayes, R. D. Farm-Scale Alcohol: Fuel for Thought. Ontario Agricultural College, **Notes on Agriculture,** 17(4):4-8, 1981.

13 Higgins, R. Methanol as a Fuel. Ontario Agricultural College, **Notes on Agriculture,** 17(4):18-20, 1981.

14 Hodgson, H. J. Fuel from Crops: Part 1, Grain and Sugar Crops. Part 2, Lignocellulosics. **Crops and Soils** 34(7 & 8): 5-7 and 5-6, 1982.

15 Lipinsky, E. S. Chemicals from Biomass: Petrochemical Substitution Options. **Science** 212:1465-1471, 1982.

16 Otten, L. Using Biomass to Dry Crops. Ontario Agricultural College. **Notes on Agriculture** 17(4):21-29, 1981.

17 Pimentel, D. Energy and Food. **BioScience** 31(11); 791, 1981.

18 Pimentel, D. Biomass Energy. **BioScience** 32(10); 769, 1982.

19 Pos, J., R. H. teBoekhorst, B. Walczak and V. Pavlicik. Design and Operation of a 1400 Litre Anaerobic Digester Utilizing Swine Manure. Ontario Agricultural College, **Notes on Agriculture** 17(4):8-18, 1981.

20 Rasmussen, W. D. The Mechanization of Agriculture. **Scientific American** 247 (No. 3);77-89, 1982

21 Rennie, D. A. Intensive Cultivation. The Long-Term Effects. **Agrologist** 8(4):20-22, 1977.

22 Stoskopf, N. C. Cultural Energy and Crop Production. (In) **Understanding Crop Production.** Reston Publishing Company, Inc., Reston, Virginia, 279-310, 1981.

23 Timbers, G. E., and N. E. Jensen. Energy Analysis of Selected Farms in Western Canada. (In) **Future Energy Requirements on Farms and Ranches.** Alberta Institute of Agrologists Seminar, Calgary, 12 pp., 1978.

Bibliography

1 Commoner, B., M. Gertler, R. Klepper and W. Lockeretz. The Effect of Recent Energy Price Increases on Field Crop Production Costs. **Center for the Biology of Natural Systems,** Washington University, Saint Louis, Missouri, 108 pp., 1974.

2 Commoner, B., M. Gertler, R. Klepper and W. Lockeretz. The Vulnerability of Crop Production to Energy Problems. **Center for the Biology of Natural Systems,** Washington University, Saint Louis, Missouri, 34 pp., 1975.

3 Green, M. B. Eating Oil. **Energy Use in Crop Production,** Westview Press, Boulder, Colorado, 205 pp., 1978.

4 Staniforth, A. R. **Cereal Straw,** Clarendon Press, Oxford, 175 pp., 1979.

Matching Engines with Fuels Developed from Agricultural Materials

by:
K. L. Walker
Chief Engineer, Advanced Engineering
Perkins Engines, England

Abstract

The development of diesel and gasolene engines and their fuels have been interwoven to a degree of interdependence. The perceived degradation of petroleum based fuels and the introduction of alternative fuels as demand for oil exceeds supply, or other political or economic factors intervene, is disturbing this relationship. This paper reviews, in the context of agricultural sources of alternative fuels, the fuel/engine options that can be pursued technically. These are set off in the light, and considering the effects, of fuel sourcing, processing, distribution and basic cost. Particular attention is given to the interactive nature of fuel specification and quality between fuel production and engine utilisation. Finally, some basic conclusions are drawn regarding the most profitable routes.

Introduction

Internal combustion gasolene and diesel engines have traditionally been designed and optimised to run on conventional petroleum based fuels. The characteristics of these fuels have also been tailored to meet the needs of engine design, resulting in a mutual interdependence. Pressure on fuel suppliers, as it increases year by year, is leading to a progressive degradation of fuel specifications which threatens the balance of this interdependence. Although this may appear insignificant in many countries, the effects are already with us in others, and worldwide, portend a long term trend downwards. The advent of alternative fuels, from various sources, as a result of political and economic issues, concerning oil supply, together with perceived long term availability problems, is further disturbing the balance. All concerned with the engine industry, whether they be government planners, fuel producers, engine and equipment manufacturers or the end user, have a part to play in this changing relationship. In the context of Ontario, this conference is a welcome opportunity to bring these groups together.

The total fuel cycle encompasses the source, processing, distribution and utilisation of the fuel in question. Any study which neglects one or more of these aspects will prove inadequate and may consequently be misleading. Whilst the brief for this paper is essentially concerned with utilisation the content has been written with an understanding that it must integrate with the total fuel concept. This is particularly illustrated in the section dealing with specification and quality control of fuels which often has a significant impact on processing and even distribution.

Fuels

In the context of agricultural wastes and resources, fuels can be divided into four categories: – gases, alcohols, vegetable oils and monoesters.

Gases are usually generated from the decomposition of agricultural wastes and largely consist of methane. Alternatively producer gas (basically CO and H_2) can be made by the partial oxidation of cellulose materials such as wood or from pre-prepared charcoal. Generally it is most economic and convenient to generate such gases close to static power units for which they are more suited. However, mobile, on-board generators or storage units have been successfully used.

The alcohols, particularly methanol and ethanol, can be made from agricultural produce. In this case methanol is usually obtained from wood, but the economics of using natural gas as a feedstock are very hard to match. The logistics of using waste wood left after timber cutting demand a transportable process plant geared mainly to producing fuel for equipment used in tree felling and hauling. Considerable argument has raged over the energy balance in the production of ethanol, but the correct choice of crop, including process energy from the waste bagasse, can provide an effective and efficient source. Barring local conditions which may favourably influence them, the cost per unit of energy will always be above that of petroleum products taken at present levels. In storage they will pick up moisture at any opportunity, which can lead to operational, and forecourt metering, problems with the customer.

Vegetable oils compete more than most fuel crops with their use for food. Indeed their price is largely ordained by the food market and secondarily by the chemical industry. All vegetable oils are blends of various triglycerides ranging from the saturated to unsaturated fatty acid radicals. Their basic characteristics are predictable from their composition and so they form a cohesive range of fuels. Deterioration during extended storage is an ever present problem, particularly in the presence of moisture when the acidity level can rise.

Monoesters are derivatives of vegetable oils obtained by reacting them with either methanol or ethanol. This alcoholysis process breaks up the large molecules based on the trihydric alcohol, glycerol, and transfers each of the three acid groups to individual methyl or ethyl radicals and releases the glycerol. The monoester molecules are consequently some one-third the molecular weight and the viscosity of the oil is typically reduced from 30-40 to 4-5 centistokes at 40°C. The cost of such fuel, whilst obviously based on the vegetable oil and alcohol production costs, need not be added to very significantly by the alcoholysis process, particularly if some offset can be made by the sale of the glycerol by-products.

Engine Options

Of the two basic engine cycles, spark ignited and compression ignited, the latter offers a wider range of variants to meet various alternative fuel options. Basically the spark ignition engine can be run on gases (with a gas carburetor) or on suitably volatile liquids (with a conventional carburetor) provided the fuels have a sufficiently high octane number to run without knock at the requisite compression ratio.

The diesel engine requires a fuel of adequate auto-ignition quality (cetane number) to provide ignition under compression temperatures and this may require suitable fuel additives with some fuels. However, it is possible with a relatively small amount of fuel, with acceptable auto-ignition quality, to initiate combustion in the cylinder, which is subsequently supported by fuel of much lower (and even negligible) auto-ignition quality. This is referred to as dual-fuelling and may be achieved by aspirating the alternative fuel via the inlet manifold or by the use of a second fuel injection system.

Another approach is to mix, blend or emulsify the alternative fuel, usually in relatively small quantities with either the parent gasolene or diesel fuel. This can degrade or enhance the total fuel properties depending on the components used. Table 1 lays out the engine options in standard form, using fuel blends (covers blends and/or emulsions) against the four fuel categories. The ticks indicate technically feasible fuel/engine options and the adjacent numbers in brackets refer to the paragraph number in the next section. Crosses indicate incompatible fuel/engine options.

It is perhaps pertinent to point out that the following assessments, whilst not explicitly drawing out all the technical data, are based on the author's company's wide ranging alternative fuels programme. All the supporting test information on compression ignition as well as much on spark ignition results from this programme. Specially developed test techniques, using highly instrumented single cylinder versions of a production engine, are described in previous papers references (1) and (2). Basically these involve sophisticated, in-cylinder measurements, coupled with digital analysis, to establish accurate assessment of rates of pressure rise, rates of heat release, noise spectra and fuel auto and network ignition properties. For some of the arrangements, particularly in the dual fuel regime, special multi-cylinder engines were built and appropriately equipped.

Fuel-Engine Options

Gases in Spark Ignition Engines

This is well established technology and has been used in practice during times of fuel shortage, for instance in Europe during the second world war. Both methane and producer gas (in the hydrogen enriched form often called water gas) work quite satisfactorily at typical gasolene engine compression ratios. It is, of course, essential to filter producer gas to protect and maintain engine life. Significant air displacement by the fuelling gas occurs, particularly with producer gas, which results in reduced engine power output. This can be recouped by pressure charging providing the engine scantlings are adequate to accept the increased gas loads.

Gases in Dual Fuelled Compression Ignition Engines

Direct in-cylinder injection of gases is not practical which leaves only the option of introducing the gas via the inlet manifold, premixed with the charge air. Onset of knock or pre-ignition limits the quantity of gas that can be introduced and consequently the level of diesel fuel substitution is constrained usually to less than 50 per cent. The fuel gas also displaces charge air thus reducing the total fuel that can be burned and the resultant maximum engine power output. Producer gas is particularly bad in this respect as carbon monoxide has a very high volume to energy ratio. Introduction of small amounts of water can increase the hydrogen content but this is a sensitive reaction requiring delicate control. Excess hydrogen, with its wide flammability limits soon leads to pre-ignition and reduced diesel substitution. A further control problem lies in the necessary interaction between the gas metering system and the fuel injection equipment. This normally disturbs the fuel pump factory setting and may therefore invalidate warranty unless the gas system is supplied as original equipment.

Alcohols in Spark Ignition Engines

This is far from a new science in that methanol has been used extensively in the past in racing engines. The basic problems that have surrounded car engine development on methanol and ethanol have been from chemical attack on fuel system and in-cylinder components, low volatility leading to poor cold starting, aldehyde emissions and poor perceived fuel consumption, although alcohol engines with raised compression ratios are generally more efficient than their gasolene counterparts. Solutions are available to all these problems and the relative success of the Brazilian ethanol Pro-alcohol programme, in spite of a number of teething problems, bears witness to this. With a forecast increase in methanol availability, and a likely reduction in price, interest in methanol as a unit fuel will grow.

Alcohols in Blends with Gasolene

More has been written in North America about "gasohol" than any other alternative fuels programme. In fact the Brazilians have been blending up to 20 per cent ethanol in gasolene for many years with only minor adjustments to engine timing being required. Both methanol and ethanol have high octane values and enhance the octane level of the gasolene with which they are blended. Blending can, however, be a problem, especially with methanol, and phase separation can occur in the presence of water. To combat this various coupling agents are often used. Field trials on methanol which are going on in several countries have tended to polarise towards a 15 percent blend or total gasolene substitution, with little interest in intermediate levels. There is a case for 85 per cent methanol, 15 per cent gasolene and high volatility components, to get over the cold starting problem. At the other end of the scale a 3 per cent methanol within a total 10 percent oxygenate blend has been proposed for Europe.

Alcohols in the Compression Ignition Engine

Alcohols are not natural compression ignition fuels having very poor auto-ignition properties. The only way they can be used as unit fuels is to dose them with ignition improving additives. The commonly known additives, mainly belonging to the nitrate group of chemicals, work quite well thermodynamically at adequate dosage rates. These rates have been progressively reduced by attention to the fuel/engine interactions, but no commercially viable additive is currently available, which relegates this to an emergency option only. Both alcohols have poor lubricity characteristics and fuel injection pumps often require that a lubricity additive is included in the fuel. This can be easily specified but does cause some logistics problems in fuel supply.

Alcohol Blends with Compression Ignition Engines

There are two main constraints to this particular option, blending alcohol with middle distillate diesel fuel and the consequential auto-ignition quality usually measured by cetane number. Methanol and hydrated ethanol will not blend under normal conditions with middle distillate fuel, without the aid of a surfactant (chemical emulsifying agent) of which there are none currently, widely and cheaply available. Ternary blending agents are an alternative in which case the fuel is essentially a three component mix. Dry ethanol will blend with middle distillate fuel up to ten per cent or even more at elevated temperatures. However, the presence of water, even in the small quantities arising from atmospheric humidity effects in storage tanks, will cause phase separation. Recourse has been taken to devices, of an "on-board" nature, which will produce micro-emulsions of alcohol and middle distillate, mechanically or hydraulically. These are effective, but are expensive and suffer from two potential problems. The first is that phase separation occurs during extended shut-down leading to problems on start-up and possible failure to start. This can be avoided by always idling and shutting down on unblended 100 percent middle distillate fuel. This implies, however, that the blend ratio of the two fuels can be altered according to load and speed conditions especially as this can also maximise the diesel fuel substitution. The second problem is that such control systems are complex and expensive and suffer from hysteresis problems due to the volume of fuel in the fuel pump and its immediate circuit.

The auto-ignition, or cetane number, level of the base middle distillate fuel is all-important, since the blended alcohol has a very low cetane number and quickly lowers the mixture auto-ignition quality, on a pro-rata basis. Should the base fuel already have a low cetane number, say around the lower forties, then there is little scope for alcohol blending. Engines will always require that blended fuels meet the minimum diesel fuel specification in terms of auto-ignition, if they are to operate satisfactorily.

Alcohol fuels under dual fuel operation in diesel engines

Under this arrangement an initial, or "firing", quantity of normal diesel middle distillate fuel is injected into the cylinder. This creates combustion and then the alcohol is injected into the already firing cylinder. This is a very effective way of obtaining high levels of diesel fuel substitution, which can exceed 90 percent under some operating conditions. Control is relatively complex and the modifications to the cylinder head design and the addition of a second fuel injection system are very expensive. The larger the engine size, the more attractive the costs can become, if based on a production engine, rather than an in-field conversion.

Vegetable Oils, Blended or as Unit Fuels in Compression Ignition Engines

A number of vegetable oils will perform, thermodynamically, quite satisfactorily in a C.I. engine. With extended running, however, they cause carboning up of injectors, particularly on direct injection engines, piston ring sticking and also attack the lubricating oil by depleting the anti-oxidation additives. Many field trials have been carried out around the world, but these problems have always appeared to some degree or other. Tests by the author's company have shown that carboning of the injectors is very largely related to the saturation level of the oil expressed as its iodine number. Fully saturated oils are much better, but all have high melting points and the fuel therefore requires heating before it can be used. High viscosity of vegetable oils causes fuel/air mixing problems and the fuel injection equipment has to be re-matched in order to optimise performance and minimise both the piston ring stick problem and lub oil attack.

Monoesters as Fuels in Compression Ignition Engines

As described earlier, monoesters are prepared by alcoholysis reaction of vegetable oils with alcohol. This produces a fuel which has improved auto-ignition properties compared with the feedstock vegetable oil, much lower viscosity and generally speaking lower melting points of the various constituent fatty acid radicals. This provides a basic cure for the injector coking and piston ring sticking, associated with unmodified vegetable oils and greatly enhances the lub oil change periods. With this good auto-ignition fuel engines run noticeably smoother and with much reduced exhaust smoke, even compared with running on conventional diesel middle distillate fuel. The minimal, if any, engine changes that are required with some typical monoester fuels make them preferred above all other biomass sourced alternative fuels.

Vegetable Oils and Monoesters Under Dual Fuel Operation in Compression Ignition Engines

This is a redundant complication in using these two fuels, since their auto-ignition properties are quite adequate (if not superior) not to require a firing quantity of middle distillate fuel. It is only mentioned to make the point that it is conceivable, technically, to use vegetable oils, and especially monoesters, as the firing fuel itself, with an inferior fuel, such as an alcohol as the main substitute fuel.

Fuel Specification and Quality Control

It has been traditional, as indicated in the introduction, to rely on the application of widely accepted standards and for the effective quality control of conventional fuels refined from petroleum feedstocks. With years of adjustment between fuel and engine, the customer has rightly come to expect high reliability and long life operation. It is equally important, therefore, when considering alternative fuels, that the same interactive process is conducted and that acceptable fuel standards are set and reliably controlled, if the customers' expectations are to be satisfied. So whilst a number of technically feasible options can be exploited under emergency conditions, much work has to be done on most options to achieve levels of performance which meet the customer's normal criteria.

This requirement for well controlled fuel processing, mitigates against the local production of alternative biomass sourced fuels in favour of larger professionally run, centralised units, where sampling and quality control methods can be economically applied. No engine, or equipment, manufacturer can be expected to warrant their product for the use of uncontrolled and unspecified fuels over which he cannot exert any influence. The likely outcome is that the engine manufacturers will negotiate acceptable standards for various alternative fuels and, indeed, this process has already started. Figures 1 and 2 outline the various parameters which are under consideration for ethanol and monoester fuel quality standards. This process will take some time and is complicated by the political problems of establishing world-wide standards.

Conclusions

Table 2 shows an an arbitrary rating for the various biomass fuel-engine operating options, based essentially on technical and convenience factors. Which options are preferred in a local situation will also depend on crop availability, price, capital and labour costs, transport logistics and general application aspects. In almost every circumstance, with a few exceptions, it is true to say that alternative fuels are, and will be for some time, more expensive than conventional petroleum based fuels. However, as demand for fuel eventually starts to exceed supply, or there is a fuel crisis, the real price of petroleum fuels will rise and alternatives will come into their own. Due to the contrary economics, only far-sighted government action and support will ensure that all will be ready when that time arrives. Study of Brazil, South Africa, New Zealand and a number of developing countries indicates that it may not be long before we, too, will need to take similar action.

References

1 "The Effects of Biomass Fuels On Diesel Engine Combustion Performance" by D. M. Bacon, N. Bacon, I. D. Moncrieff and K. L. Walker – **IV Alcohol Fuels Symposium** – Guaraja – October 1980.

2 "The Use of Vegetable Oils in Straight and Modified Form as Diesel Engine Fuels" by D. M. Bacon, F. Brear, I. D. Moncrieff and K. L. Walker – **ICEUM III Conference,** Berlin – October 1981.

Table 1

	SPARK IGNITION		COMPRESSION IGNITION		
	STD.	BLEND	STD.	BLEND	DUAL FUEL
GASES	✓(1)	X	X	X	✓(2)
ALCOHOLS	✓(3)	✓(4)	✓(5)	✓(6)	✓(7)
VEG. OILS	X	X	✓(8)	✓(8)	✓(10)*
MONOESTERS	X	X	✓(9)	✓(9)	✓(10)*

*REDUNDANT COMPLICATION

Table 2

	SPARK IGNITION		COMPRESSION IGNITION		
	STD.	BLEND	STD.	BLEND	DUAL FUEL
GASES	●●				●
ALCOHOLS	●●	●●●	●●	●●	●
VEG. OILS			●●	●●	●
MONOESTERS			●●●	●●●	●

● TECHNICALLY COMPLEX AND/OR EXPENSIVE ENGINE MODIFICATIONS
●● TECHNICALLY ACCEPTABLE BUT REQUIRES SIGNIFICANT ENGINE MODIFICATIONS
●●● PREFERRED - MINIMUM ENGINE IMPACT

Ethanol Quality Standards

figure 1

	SPECIFICATION CNP 01/79	MOTOR INDUSTRY PROPOSAL
ETHANOL % wt	MIN 91.1 MAX 93.9	MIN 91.9
DENSITY AT 20°C kg/l	MIN 0.8074 MAX 0.815	DEPENDING ON ETHANOL CONT
RESIDUALS mg/l AT DISTILLED TEMP°C	5.0 105	20 200
ACIDS mg/l	30	10
ALDEHYDES mg/l	60	TO BE AGREED UPON
ESTERS mg/l	80	100
HIGHER ALCOHOLS mg/l	60	NO LIMITATION
COPPER	NOT SPECIFIED	NONE
ASH	NOT SPECIFIED	NONE

Monoester Quality Standards

figure 2

SPECIFICATION	CONTROL
GLYCERIDES (MONO, DI, TRI)	CONVERSION EFFICIENCY
SOAP UNSAPONIFIABLES (INCLUDING SOAP)	NON-MONOESTER RESIDUALS (EG CATALYST)
FLASH POINT	ALCOHOL CONTENT
ACIDS	FREE FATTY ACIDS REACTION NEUTRALISATION ACID
WATER	STORAGE STABILITY
CFPP CLOUD POINT C_{20}+ESTER CONTENT	LOW TEMPERATURE OPERATION
IODINE NUMBER SAPONIFICATION NUMBER	MONOESTER CHARACTERISTICS

Energy Production by Anaerobic Digestion of Livestock Wastes

by:
H. D. Monteith, M.Sc., P.Eng.
R. J. Rush, M.A.Sc., P.Eng.
A. R. Stickney, CET
Canviro Consultants Ltd.
Kitchener, Ontario

Abstract

Anaerobic digestion is a biological process which converts organic matter into gas (consisting of primarily methane and carbon dioxide) with considerable energy value (typically 22.6 MJ/m^3). Livestock wastes have been shown to be particularly amenable to anaerobic digestion. CANVIRO Consultants Ltd. has designed five full-scale anaerobic digestion systems for farms to recover either biogas energy alone, or biogas energy along with Single Cell Protein (SCP) recovery from the digester effluent. These systems have been developed for 5,000 head and 160 head beef feedlots, 300 sow and 2,400 sow farrow-to-finish swine operations and a swine finishing operation that markets 3,500 hogs per year. At the present time one system has been operational for two years, and a second system is nearing the end of construction. Two others are expected to begin construction in early 1983.

The net energy benefit from installation of anaerobic digesters for the farms studied is estimated to range from 6.60 to 38.16 GJ/d. Capital costs for these designs range from $125,000 to $1,222,000. Estimated straight-line payback periods without interest for these digestion and protein recovery facilities is typically 5 years, at present energy prices.

Installation of anaerobic digestion systems on small to medium sized farms for energy recovery is not yet highly attractive economically in Ontario because of present energy costs. Rising energy prices should make this proven technology more cost-effective for farms. Matching farm energy requirements with biogas energy production remains one of the most difficult problems to overcome in farm digester applications.

Introduction

Anaerobic digestion is a biological fermentation process in which organic matter is decomposed in the absence of air to yield methane and carbon dioxide gas. It occurs naturally where organic material exists in the absence of air under conditions amenable to microbial processes. Bacteria convert complex materials such as carbohydrates and lipids to much simpler compounds, which are then reduced to methane and carbon dioxide, which together are commonly known as biogas (approx. 65% methane, 35% carbon dioxide). The general technology of anaerobic digestion is well-known, and has been applied for many years in the treatment of domestic sewage sludges (Schlenz 1947, Buswell 1947). It has also been used in developing countries to convert wastes to energy for lighting, cooking and fueling internal combustion engines for water pumping (Pyle 1979, MacGarry 1980, Sharma 1980). Recently, research and development studies have shown that the bacteria can be recovered by centrifugation from the digestion effluent, and that this Single Cell Protein (SCP) is valuable as an animal feed supplement (CANVIRO 1980, 1982b, 1982c).

The benefits of anaerobic digestion for waste treatment are summarized in Table 1. From being primarily a waste treatment process which reduced pollution, odour and pathogenic organisms, anaerobic digestion now attracts most interest because of its energy-producing potential, and, in some cases, production of Single Cell Protein as a livestock feed supplement.

Benefits of Anaerobic Digestion

Table 1

- Energy Production
- Pollution Control
- Odour Reduction
- Pathogen Reduction
- Single Cell Protein Recovery

Due to a rapid increase in energy prices in the past decade, much interest has focused on alternatives to fossil fuels. Only in the last 3 or 4 years however, has significant attention been paid to anaerobic digestion as a feasible energy alternative in industrial nations. As noted in Table 2, biogas from anaerobic digesters can replace propane, natural gas, fuel oil, diesel or gasoline. Possible applications of biogas energy include boiler fuel, stationary engine fuel, vehicle fuel, crop drying and electricity generation.

Energy Recovery by Anaerobic Digestion

Table 2

Biogas Can Replace:	Propane Natural Gas Fuel Oil Diesel Fuel Gasoline
Biogas Can Be Used for:	Boiler Fuel Stationary Engine Fuel Crop Drying Electricity Generation Vehicle Fuel

Anaerobic digestion technology can be applied to a variety of industrial and agricultural wastes. For example, biogas can be produced from livestock manure, high strength industrial wastes and crop residues and biomass, as well as wastewater sludges (Table 3). Applications of anaerobic technology are currently under consideration, primarily in the food and beverage industry, but no full-scale industrial applications of anaerobic digestion, to the authors' knowledge, is operational at present in Canada. For this reason, the discussion of this paper will deal with the development of full-scale anaerobic digestion technology applied to agricultural wastes.

Applications of Anaerobic Digestion Technology

Table 3

Biogas Can Be Produced From:	Livestock Manure High Strength Industrial Waste Crop Residues and Biomass Wastewater Sludges

Agricultural operations in Ontario, and Canada in general, have a higher inherent space heating and electrical requirement than other countries, making them particularly amenable to the utilization of biogas generated from anaerobic digestion. The non-renewable resources saved by widespread utilization of farm-scale anaerobic digestion and protein recovery systems could make a significant contribution to Canada's goal of energy self-sufficiency. In addition to the energy saved by utilization of the biogas, energy will be saved by the displacement of protein supplements with recovered Single Cell Protein from the digester effluents. The SCP cake can be blended with conventional rations to reduce the soybean protein requirements for finishing hogs and beef cattle.

Anaerobic digestion systems also reduce the pollution associated with livestock. The increasing scale and intensity of agribusiness in Ontario, and Canada in general, results in an increasing, and in some areas a critical requirement for waste handling and disposal systems that reduce their environmental impact on the immediate surroundings. With significant reductions in odour and/or water pollution, plus the ease of handling and pumping of the effluent resulting from the digestion of animal waste, a positive reduction in the environmental impact of manure handling is obtained. Anaerobic digesters can thus provide a dual benefit to farms in terms of reduced environmental impacts, and reduced costs for energy and feeds.

In Canada, the technical aspects of applying anaerobic digestion processes to agriculture are relatively well understood. The major challenge facing the designers of anaerobic systems is in determining the optimum use of biogas produced for farm consumption. Design studies have shown that the energy potential from digestion of livestock wastes is frequently greater than the needs of the farm (CANVIRO Consultants Ltd. 1982b). Potential revenues or savings are consequently reduced when excess biogas is vented or flared.

In this paper, five farm scale anaerobic digestion systems designed by CANVIRO Consultants Ltd. are discussed to provide an overview of the status of this energy conservation technology as applied to agricultural wastes.

Facility Designs

5,000 Head Beef Feedlot

The first successful full-scale anaerobic digestion facility on a Canadian farm was designed and operated by CANVIRO Consultants Ltd. between 1979 and 1981. The system was constructed at a 5,000 head beef feedlot in Ontario. The facility was initially designed to hande 64 m^3/d of liquid manure (40% of feedlot's manure) in a digestion tank of 636 m^3 liquid capacity. Typical biogas production at an operating temperature of 35°C was 543 m³/d, having an energy value of 12.30 GJ/d.

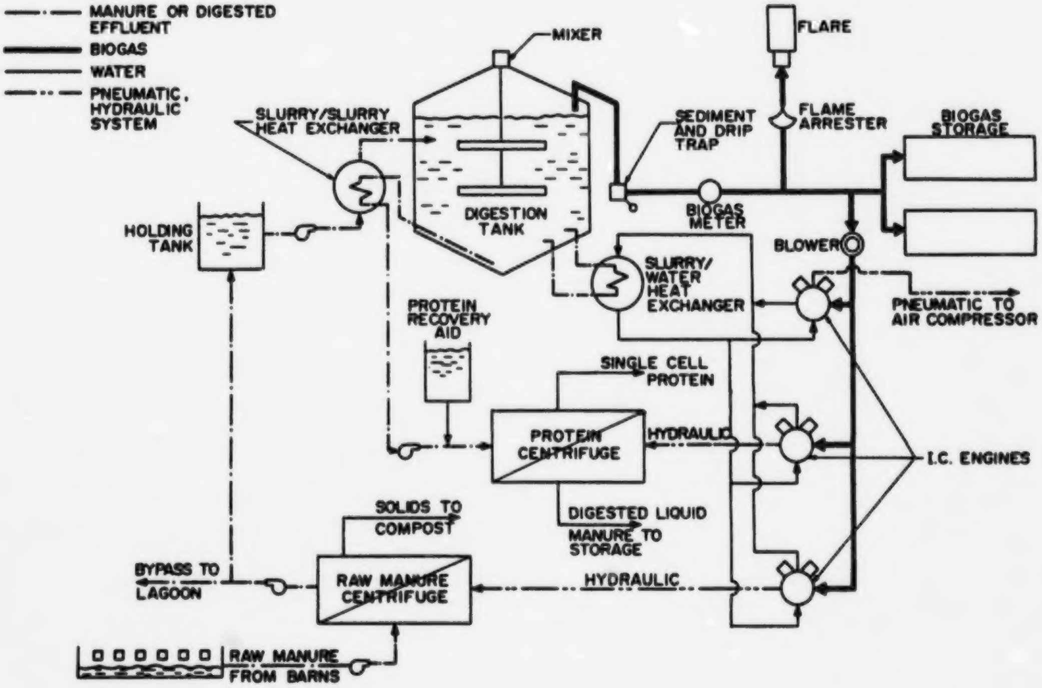
The biogas produced was used to fuel a boiler and provided live steam for preheating the raw manure to 35°C before entering the digester, and also for direct injection into the tank to maintain the process temperature at 35°C. Excess biogas was vented to the flare.

In the original economic analysis of the system, it was determined that recovery of Single Cell Protein (SCP) from the digester effluent was the major economic incentive for this facility. Therefore most early process optimization was concerned with maximizing the recovery of Single Cell Protein. During this time, however, potential uses for the biogas were being evaluated to determine the optimum use of the biogas energy.

It became clear that the optimized process could operate at a much higher loading rate than in the initial design, producing excessive amounts of biogas that had to be wasted at the flare. (The biogas production rate for the optimized system is approximately 1,270 m³/d having an energy value of 28.72 GJ/d.) After extensive evaluations of the options for use of the biogas energy, it was determined the energy could be best used to power internal combustion engines. The system was modified by removing the boiler, installing a hot water/digested manure heat exchanger, a raw manure/digested manure heat exchanger, and installing three internal combustion engines to use the biogas. One engine is currently used to drive the farm's air compressor and a series of air operated pumps, while the remaining two engines are used to drive the hydraulic systems that run the two centrifuges in the farm's anaerobic digestion and protein recovery system. The engines' cooling jacket water is recirculated in the heat exchanger to maintain the process temperature. A schematic diagram showing the digestion system with modifications for optimum energy use appears in Figure 1.

Schematic Diagram of Anaerobic Digestion and Protein Recovery System for a 5,000 Head Beef Feedlot in Ontario

figure 1



Energy Analysis of Anaerobic Digestion and Protein Recovery System for 5,000 Head Beef Feedlot, Ontario

Table 4

Energy Use (average)		
a) Manure Heating	13.96	GJ/d
b) Digester Heat Loss	1.16	GJ/d
TOTAL	15.12	GJ/d
Direct Energy Production/Recovery		
a) Heat Recovery from Digester Effluent	6.33	GJ/d
b) Heat Recovery from I.C. Engines	10.81	GJ/d
c) Heat Recovery from Hydraulic and Pneumatic Lines	1.58	GJ/d
d) Displacement of electrical demand	20.12	GJ/d
SUBTOTAL	38.84	GJ/d
Indirect Energy Savings		
e) Environmental Pollution Reduction	6.90	GJ/d
f) Protein Feed Replacement	7.54	GJ/d
SUBTOTAL	14.44	GJ/d
TOTAL ENERGY BENEFIT	53.28	GJ/d
AVG. ANNUAL NET ENERGY BENEFIT	38.16	GJ/d

An analysis of energy production or savings and energy requirements for the anaerobic digestion and protein recovery system is summarized in Table 4. The average annual heating requirements for the digestion system are 13.96 GJ/d for manure heating and 1.16 GJ/d for heat losses through the digester shell, for a total of 15.12 GJ/d. On the coldest winter days, the total heat requirement is estimated at 19.41 GJ/d.

It should be noted that in the worst case (i.e. coldest winter day), an estimated direct energy shortfall of 0.69 GJ/d may be experienced. In this case, auxiliary fuel will be used to drive the internal combustion engines to provide the necessary heat input.

Both direct and indirect energy savings have been estimated. Direct heat recovery from the digester effluent, from the internal combustion engines and from the hydraulic oil and compressed air levels are estimated to be 6.33, 10.81 and 1.58 GJ/d, respectively. Use of biogas in the I.C. engines to drive the pneumatic and hydraulic systems at the farm will displace approximately 20.12 GJ/d of energy previously consumed by electric motors. Additional energy credits have been calculated based on the reduction of 5-day biochemical oxygen demand (BOD_5) by the digester compared to standard aerobic treatment (approx. 6.90 GJ/d) and on recovery of Single Cell Protein which eliminates the energy required for growth of soybean and production of urea (approx. 7.54 GJ/d). Indirect energy benefits are thus estimated at 14.44 GJ/d. The total energy benefit of the anaerobic digestion and protein recovery system is 53.28 GJ/d. The average daily net energy benefit of this system is therefore 38.16 GJ/d.

The economic analysis for this feedlot's new facility is summarized in Table 5. The capital cost for the anaerobic digestion and protein recovery system is $476,430. Major capital items are the protein recovery centrifuge and digestion tank with mixer. Annual operating and maintenance costs for this system total approximately $49,500, of which the chemical aid for protein recovery is the major expense. Major revenues resulting from installation of this system are primarily for replacement of conventional protein sources ($238,000 per year) and replacement of electricity by hydraulic and pneumatic systems ($41,800 per year). Total savings are thus $281,600 per year when space heating savings are included. The net profit for this facility is $232,100 per year due to installation of the digestion and protein recovery system. The resulting straight-line payback period (without interest) is ony 2.1 years making the facility an attractive investment. The value of the recovered Single Cell Protein, rather than the energy savings, makes the payback period short for a feedlot of this size.

300 Sow Farrow-To-Finish Operation, Stratford, Ontario

A second anaerobic digestion and protein recovery system in Ontario, designed by CANVIRO Consultants Ltd. was put into operation in January 1983. The farm is a 300 sow farrow-to-finish operation marketing 6,000 hogs per year. The system is designed to treat $14m^3/d$ of swine waste (pumped from pits beneath slatted floor barns) in a digestion tank having 205 m^3 of active liquid volume. The anticipated average biogas production is 524 m^3/d, which has a gross energy value of 11.8 GJ/d.

In designing this system it was determined that the best use of the digester biogas was for generation of electricity for on-farm utilization. Additional energy recovery from warm process water for heating an office and workshop has also been planned. The digestion system for this farm includes recovery of SCP from the digester effluent for refeeding to the swine. A schematic diagram of this anaerobic digestion and protein recovery system appears in Figure 2. An interesting energy-conserving feature of this system is the construction of the digestion tank such that it is completely below grade to reduce heat losses through the tank walls and roof.

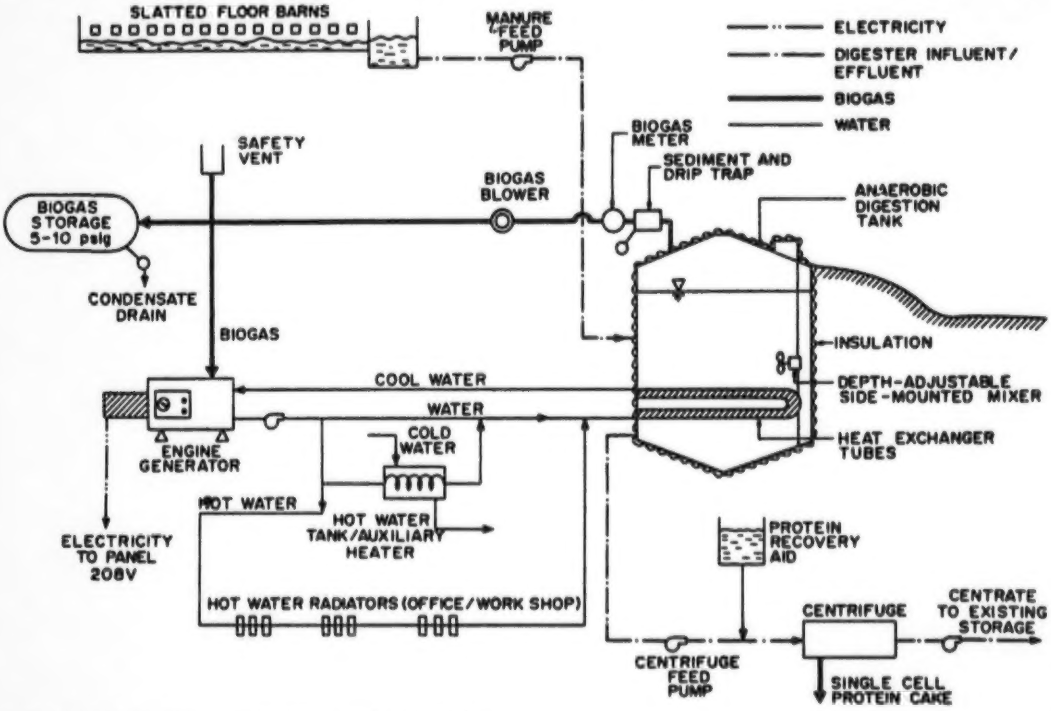
Economic Analysis of Anaerobic Digestion and Protein Recovery System for 5,000 Head Beef Feedlot, Ontario

Table 5

A. Capital Costs	
Manure Feed System	$ 8,430
Digestion Tank System	85,385
Biogas Collection and Storage	15,735
Biogas Conversion System	49,090
Controls and Instrumentation	4,410
Building and Site Preparation	21,880
Protein Recovery System	165,680
Electrical/Mechanical Contract	50,660
Engineering and Contingency	75,160
	TOTAL $476,430
B. Annual Operating and Maintenance Costs	
Fixed Costs	$10.700
Operating Costs and Supplies	28,200
Labour	10,600
	TOTAL $49,500
C. Annual Revenues	
Electricity Replacement	$ 41,800
Space Heating	1,800
Protein Recovery	238,000
	TOTAL $281,600
D. Net Annual Profit	
Annual Revenues – Annual O & M Costs = $281,600 – $49,500 = $232,100	
E. Calculated Straight-Line Payback Period (without interest)	
Capital Cost/Annual Profit = $476,430/$232,100 = 2.1 years	

Schematic Diagram of Anaerobic Digestion and Protein Recovery System for a 300 Sow Farrow-to-Finish Swine Operation in Ontario

figure 2



Estimated energy requirements and savings for this facility are summarized in Table 6.

Energy Analysis of Anaerobic Digestion and Protein Recovery System for 300 Sow Farrow-to-Finish Hog Farm, Ontario

Table 6

Energy Use (average)			
a) Manure Heating		1.57	GJ/d
b) Digester Heat Loss		0.56	GJ/d
	TOTAL	2.13	GJ/d
Direct Energy Recovery			
a) Elecrical Generation		13.00	GJ/d
b) Low Grade Heat for Office, Shop, etc.		5.04	GJ/d
	SUBTOTAL	18.04	GJ/d
Indirect Energy Savings			
c) Environmental Pollution Reduction		1.02	GJ/d
d) Protein Feed Replacement		1.25	GJ/d
	SUBTOTAL	2.27	GJ/d
	TOTAL ENERGY BENEFIT	20.31	GJ/d
	NET ENERGY BENEFIT	18.17	GJ/d

On a typical operating day, the digestion system requires 2.13 GJ/d of energy, consisting of 1.57 GJ/d for manure heating and 0.56 GJ/d for digester shell losses. Direct energy savings, resulting from electrical generation and recovery of waste heat from the engine jacket water, are estimated at 13.00 GJ/d and 5.04 GJ/d, respectively. Indirect energy savings from pollution reduction and replacement of protein feeds are 1.02 GJ/d and 1.25 GJ/d, respectively. The total energy benefit to this hog farm is thus 20.31 GJ/d on average, resulting in a net energy benefit of 18.18 GJ/d.

The economic analysis for this farm's anaerobic digestion and protein recovery system is summarized in Table 7. The capital outlay for a centrifuge in the protein recovery system represents a major portion of the total capital cost of $223,000. The resulting annual operating costs are approximately $12,700. The estimated savings or revenues resulting from the digestion and protein recovery system are estimated at approximately $55,200 per year. The net profit is estimated at $42,450/year. The payback period for this facility is estimated at 5.3 years.

In this system the recovered SCP, rather than energy, provides the main incentive for anaerobic digestion. Protein recovery for swine farmers is less favourable than for beef farmers because the swine cannot use non-protein nitrogen present in the recovered SCP whereas ruminants can. It is apparent that the incentives and payback periods for building farm anaerobic digestion systems will not improve until energy prices in Ontario and other parts of Canada rise closer to world prices.

Demonstration of Anaerobic Fixed Film Technology for Swine and Beef Manure, Kemptville Agricultural College

In recent years, considerable interest has focused on fixed film anaerobic digestion technology because of reported higher loading rates and biogas production rates. CANVIRO Consultants Ltd. was awarded a contract from the Ontario Ministry of Agriculture and Food in 1982 to design an anaerobic fixed film prototype system that could treat either beef or swine manure. The

Economic Analysis of Anaerobic Digestion and Protein Recovery System for 300 Sow Farrow-to-Finish Swine Farm, Ontario

Table 7

A. Capital Costs	
Manure Feed System	$26,000
Digestion Tank System	37,000
Biogas Storage and Utilization System	46,200
Protein Recovery System	73,500
Building	8,000
Electrical/Mechanical Contract	12,500
Engineering and Contingency	19,800
	TOTAL $223,000
B. Annual Operating and Maintenance Costs	
Fixed Costs	$ 3,500
Materials and Supplies	5,800
Labour	3,400
	TOTAL $12,700
C. Annual Revenues	
Electricity Generation	$18,900
Low-Grade Heat (Office, Shop, House)	3,000
SCP Recovery for Refeeding	33,250
	TOTAL $55,150

D. Net Annual Profit

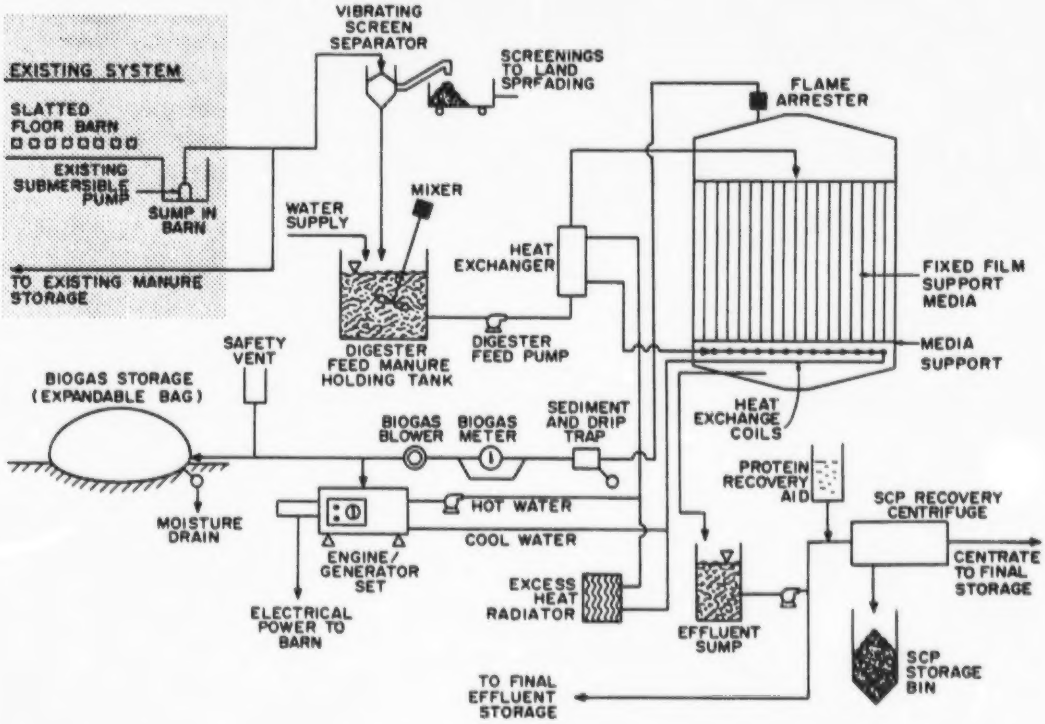
Annual Revenues – Annual O & M Costs
= $55,150 – $12,700
= $42,450

E. Calculated Straight-Line Payback Period (without interest)

Capital Cost/Annual Profit
= $223,000/$42,450
= 5.3 years

Schematic Diagram of Fixed Film Anaerobic Digestion and Protein Recovery Demonstration Facility at Kemptville College

figure 3



objectives of this study are to: (1) construct a digester that will demonstrate to the private and public sectors the applicability of fixed film technology; (2) to install a SCP recovery system to demonstrate the recovery of protein from the effluent of the fixed film digester; and (3) to install both a biogas fueled electrical power generation system, and a biogas-fueled boiler to demonstrate the displacement of non-renewable energy supplies by biogas from the fixed film system.

An anaerobic digestion and protein recovery system using fixed film technology was designed for a 160 head beef feedlot in this demonstration. However, because previous economic evaluations (CANVIRO Consultants Ltd. 1982) had shown a digestion facility for the size of this demonstration project to be financially unfeasible, a design facility for a typical 500 head beef feedlot was selected for analysis. Generation of electricity for on-site use was determined to be the optimum method of energy conversion. The digester size was established as 144 m^3, resulting in a hydraulic retention time of 4 days. The estimated biogas production from this facility was 345 m^3/d, having a gross energy value of 2,840 GJ/year. The facility design is shown schematically in Figure 3.

Analysis of the energy requirements and savings for this process design is presented in Table 8. Energy uses on the farm, including manure heating requirements and heat losses through the digester shell, total 3.29 GJ/d. Conversely, energy savings, which are represented by generated electricity, recovered hot water, pollution reduction and protein feed replacement, are estimated at 13.73 GJ/d. The net energy benefit to the 500 head beef feedlot in this conceptual design is therefore 10.44 GJ/d. The average net energy savings from direct energy recovery are approximately 5.91 GJ/d.

Energy Analysis of Anaerobic Fixed Film Digester for a 500 Head Beef Feedlot

Table 8

Energy Use (average)			
a) Manure Heating		2.82	GJ/d
b) Digester Heat Loss		0.47	GJ/d
	TOTAL	3.29	GJ/d
Energy Recovery Savings			
a) Elecrical Generation		5.47	GJ/d
b) Recovered Hot Water		3.73	GJ/d
	SUBTOTAL	9.20	GJ/d
Indirect			
c) Protein (True Protein and Non-Protein Nitrogen) Feed Replacement		2.18	GJ/d
d) Environmental Pollution Reduction		2.35	GJ/d
	SUBTOTAL	4.53	GJ/d
	TOTAL ENERGY BENEFIT	13.73	GJ/d
	NET ENERGY BENEFIT	10.44	GJ/d

The economic analysis for an anaerobic fixed film digestion system suitable for a 500 head beef feedlot is summarized in Table 9. Total capital costs for this facility are estimated at $191,300. The estimated annual operating and maintenance costs are approximately $12,850. Revenues and savings accruing to the feedlot from installation of the digestion facility are estimated at approximately $46,600, as a result of electricity generation, space heating and recovery of SCP. This system thus has a net annual profit of $33,700. The calculated payback period for this digestion facility is 5.7 years, which is similar in magnitude to the payback for the 300 sow farrow-to-finish operation in Ontario described above.

Economic Analysis of Anaerobic Fixed Film Digester for a 500 Head Beef Feedlot

Table 9

A. Capital Costs	
Manure Feed System	$ 4,400
Digestion System	29,900
Biogas Handling and Utilization System	46,200
Protein Recovery System	73,500
Building	8,000
Electrical/Mechanical Contract	12,500
Engineering and Contingency	16,800
	TOTAL $191,300
B. Annual Operating and Maintenance Costs	
Fixed Costs	$ 2,900
Materials and Supplies	6,550
Labour	3,400
	TOTAL $12,850
C. Annual Revenues	
Electricity Generation	$ 7,950
Space Heating	1,000
SCP Recovery for Refeeding	37,600
	TOTAL $46,550

D. Net Annual Profit

Annual Revenues – Annual O & M Costs
= $46,550 – $12,850
= $33,700

E. Calculated Straight-Line Payback Period (without interest)
Capital Cost/Annual Profit
= $191,300/$33,700
= 5.7 years

P.E.I. Swine Farm (3500 Market Hogs/Year)

The anaerobic digestion facility designed for this farm on Prince Edward Island calls for energy recovery only, with no Single Cell Protein production. The major design objectives were i) to convert swine waste to biogas for electricity generation; ii) to use the electricity generated in on-site applications with excess electricity sold to the provincial utility; and iii) to recover waste heat from the engine-generator to heat a workshop, supplement home heating requirements, and run a grain-drying operation. The expected manure production from this farm, which markets 3,500 hogs annually, is 19 m³/d of swine waste. The estimated biogas production from this waste is 432 m³/d having a gross energy value of 3,556 GJ/year.

A schematic diagram of the proposed system is contained in Figure 4. Raw manure from pits beneath the slatted floor barns is passed through a vibrating screen separator and then pumped into the digester. Digested manure is pumped to an existing storage lagoon for eventual use as fertilizer. Biogas from the digesting manure is delivered by a gas booster to a low pressure storage system. From there it is used by the engine generator as required. Hot water from the engine generator is used to heat the digestion tank, workshop, farmhouse and a grain dryer. The design also calls for installation of the digestion tank partially in-ground to minimize heat losses through the digester shell.

The energy analysis for this facility is summarized in Table 10. Uses of energy within the digestion system total 3.93 GJ/d, including manure heating, digester shell heat loss, and consumption of electricity. Energy recovered from the system includes 6.85 GJ/d for generation of electricity and 5.04 GJ/d for hot water reuse. An environmental energy credit for reduction of pollution by the anaerobic process is 0.84 GJ/d. The total and net energy benefits for this system are thus 12.73 GJ/d and 8.80 GJ/d, respectively.

Energy Analysis of Anaerobic Digestion System for P.E.I. Swine Farm (3,500 Market Hogs/Year) Table 10

Energy Use			
a) Manure Heating		1.99	GJ/d
b) Digester Heat Loss		0.82	GJ/d
c) Electricity Consumption		1.12	GJ/d
	TOTAL	3.93	GJ/d
Direct Energy Recovery			
a) Elecrical Generation		6.85	GJ/d
b) Hot Water Reuse		5.04	GJ/d
	SUBTOTAL	11.89	GJ/d
Indirect Energy Savings			
d) Environmental Pollution Reduction		0.84	GJ/d
	TOTAL ENERGY BENEFIT	12.73	GJ/d
	NET ENERGY BENEFIT	8.80	GJ/d

Economic Analysis of Anaerobic Digestion System for P.E.I. Swine Farm (3,500 Market Hogs/Year)

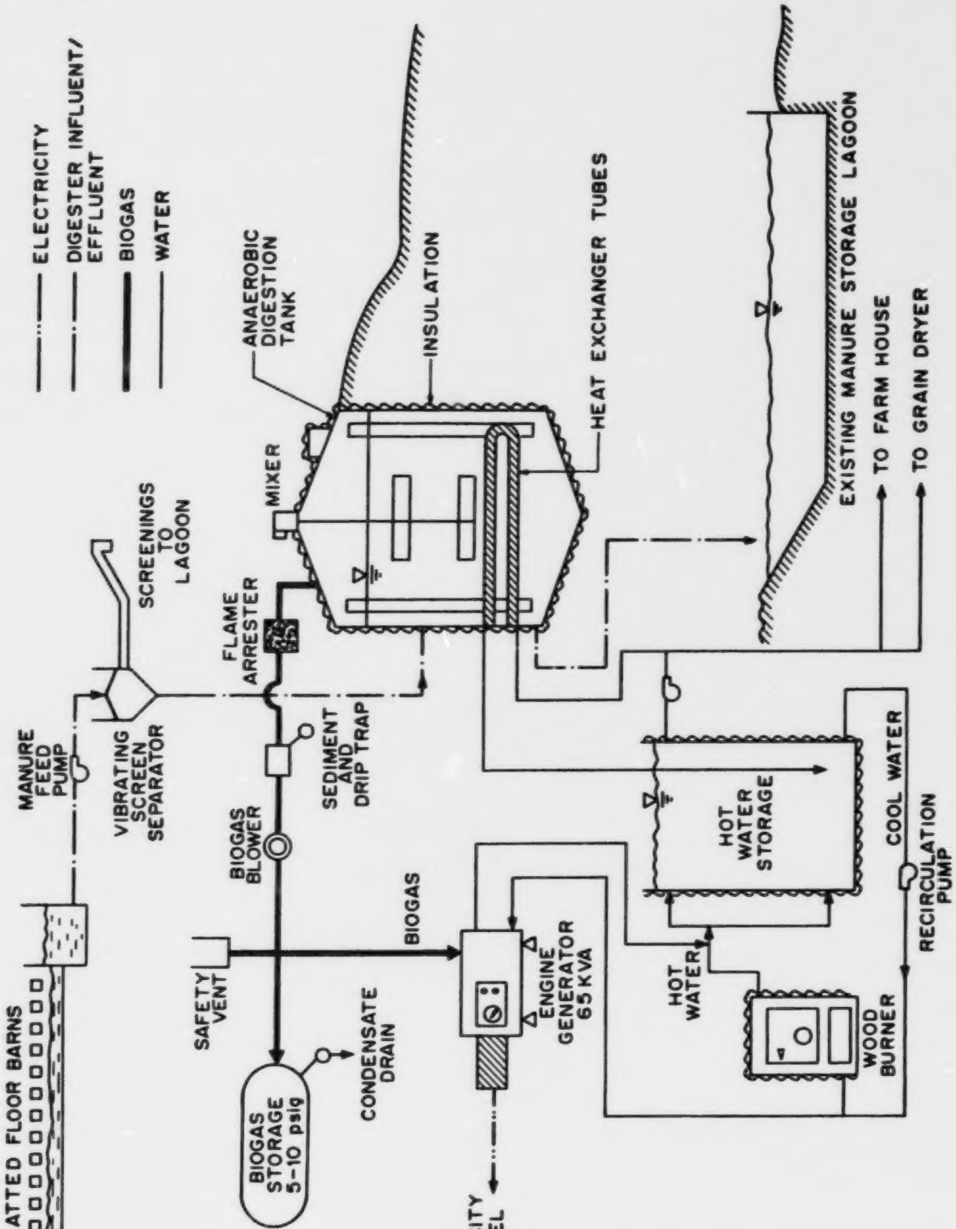
Table 11

A. Capital Costs	
Manure Feed System	$10,000
Digestion Tank System	50,000
Biogas Storage and Utilization System	37,500
Site Work	500
Electrical/Mechanical Contract	5,500
Engineering and Contingency	21,000
	TOTAL $125,000
B. Annual Operating and Maintenance Costs	
Fixed Cost	$ 2,750
Materials and Supplies	6,000
Labour	1,700
	TOTAL $10,450
C. Annual Revenues or Savings	
On-farm Electrical Use	$17,400
Sale of Electricity to Utility	7,250
Heat Recovery from Hot Water	7,200
	TOTAL $31,850
D. Net Annual Profit	
Annual Revenues – Annual O & M Costs = $31,850 – $10,450 = $21,400	
E. Calculated Straight-Line Payback Period (without interest)	
Capital Cost/Annual Profit = $125,000/$21,400 = 5.8 years	

Table 11 summarizes the economic analysis of the anaerobic digestion system for the P.E.I. swine farm. The capital cost of this system is estimated at $125,000. Major capital expenditures include the digestion tank and the engine generator. Annual operating and maintenance costs are determined to be $10,450. Annual revenues or savings are estimated to total $31,850, comprised of savings from on-farm electricity consumption, sale of electricity to the provincial utility and recovery of heat from the engine jacket water. This system thus shows a net annual profit of $21,400 which corresponds to a straight-line payback period of 5.8 years. This system has a payback period nearly as short as the others decribed above despite no revenues from protein recovery. The major difference in economic viability without protein recovery is the higher energy price in P.E.I. as opposed to Ontario.

Schematic Diagram of the Anaerobic Digestion and Electrical Power Generation System for a P.E.I. Swine Farm

figure 4



2,400 Sow Farrow-To-Finish Swine Operation, Manitoba

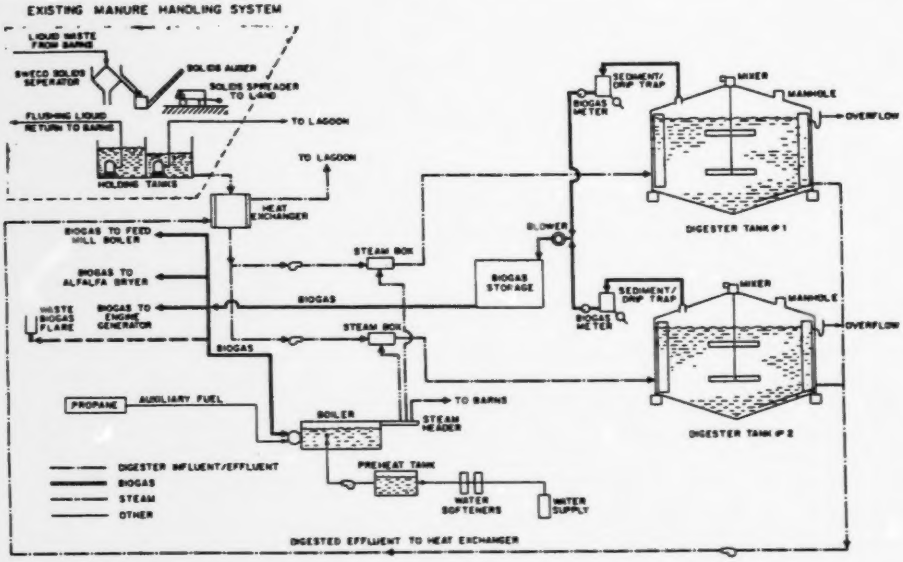
An anaerobic digestion system has been designed to treat the wastes from a 2,400 sow farrow-to-finish operation in Manitoba. The swine on this farm generate approximately 364 m^3/d of manure. The objectives for this system are to eliminate propane use in the finishing barn, in the boiler, at a nearby feedmill and in the dry sow and farrowing barns. The biogas is also to be used in an alfalfa dehydration/corn dryer system during summer months, and to fuel an electrical power generation system to provide electricity for on-site use. The digestion facility is estimated to produce 4,224 m^3/d of biogas, which have an approximate energy value of 96.2 GJ/d.

The manure on this farm is initially treated to remove solids by a vibrating screen separator as shown in Figure 5. The liquid manure, temporarily retained in holding tanks after screening, is pumped to a twin set of digesters (each 14.5 m dia. by 11 m high) by way of an influent/effluent heat exchanger. Digested effluent is pumped to existing storage lagoons for periodic spray irrigation. Biogas from the digester is cleaned, metered and sent to low pressure storage by a gas booster. The biogas can then be used directly in the feedmill boiler, in the alfalfa dryer, the engine/generator, and the digestion system boiler. The latter boiler provides steam for heating the various barns and influent to the digester itself.

The energy analysis of this digestion facility appears in Table 12. Heating of the swine manure consumes 12,320 GJ/year, whereas digester shell heat losses and electricity consumption are valued at 2,190 and 1,920 GJ/year, respectively. Total energy use in the digestion system for this farm is thus 16,430 GJ/year. A number of direct energy savings on this farm are evident. Replacement of propane used by feedmill boiler results in approximately 4,460 GJ/year savings, while running an alfalfa dryer or an engine/generator results in savings of 10,530 GJ/year and 6,560 GJ/year, respectively. Generation of steam to heat barns is estimated to reduce energy demands by 3,890 GJ/year. An additional energy credit of 3,040 GJ/year was assigned for reduction of pollution and odour. The total energy benefit to the farm for this digestion system is thus 28,160 GJ/year; the net energy benefit is 11,730 GJ/year (32.1 GJ/d).

Schematic Diagram of the Anaerobic Digestion and Energy Recovery Facility for a 2,400 Sow Farrow-to-Finish Swine Operation in Manitoba

figure 5



Energy Analysis of Anaerobic Digestion System for 2,400 Sow Farrow-to-Finish Operation in Manitoba

Table 12

Energy Use		
a) Manure Heating	12,320	GJ/year
b) Digester Heat Loss	2,190	GJ/year
c) Electricity Consumption	1,920	GJ/year
TOTAL USE	16,430	GJ/year
Direct Energy Savings		
a) Feed Mill	4,140	GJ/year
b) Barn Heating	3,890	GJ/year
c) Alfalfa/Corn Drying	10,530	GJ/year
d) Electricity Generation	6,560	GJ/year
SUBTOTAL	25,120	GJ/year
Indirect Energy Savings		
d) Environmental Pollution Reduction	3,040	GJ/year
TOTAL ENERGY BENEFIT	28,160	GJ/year
NET ENERGY BENEFIT	11,730	GJ/year

The economic analysis of the digestion system designed for this Manitoba farm is presented in Table 13. The total capital cost for this facility is estimated at $1,222,000. Major capital expenditures include the digestion tanks and mixers, biogas utilization systems including a boiler, an alfalfa dehydrator, and an engine-generator. Annual operating costs are approximately $51,800.

Revenues or savings arising from this system are credtis for eliminated propane requirements. Savings from heating the feedmill are approximately $47,700 and from heating the barns, $44,900. Electrical generation to reduce power from the Manitoba utility is estimated at $24,600. Profit from the sale of dehydrated alfalfa represents the greatest source of revenue at $228,300 per year. Total revenues and savings from this system are thus $345,500 per year. The net annual profit for this facility is $293,700, which results in a calculated straight-line payback period of 4.2 years.

Economic Analysis of Anaerobic Digestion System for 2,400 Sow Farrow-to-Finish Operation, Manitoba

Table 13

A. Capital Costs	
Boiler and Steam System	$ 47,500
Manure Feed System	72,600
Biogas Collection and Storage System	25,950
Biogas Utilization Systems	269,800
Digester Tank System	400,500
Control and Instrumentation System	14,100
Control Building	16,000
Dryer Building	25,000
Electrical/Mechanical Contract	130,000
Engineering and Contingency	221,000
	TOTAL $1,222,000
B. Annual Operating and Maintenance Costs	
Fixed Costs	$17,400
Materials and Supplies	13,500
Labour Costs	20,900
	TOTAL $51,800
C. Annual Revenues or Savings	
Heating Feed Mill	$ 47,700
Heating Barns	44,900
Sale of Dried Alfalfa or Corn	228,300
Electricity Generation	24,600
	TOTAL $345,500

D. Net Annual Profit

Annual Revenues – Annual O & M Costs
= $345,500 – $51,800
= $293,700

E. Calculated Straight-Line Payback Period (without interest)

Capital Cost/Annual Profit
= $1,222,000/$293,700
= 4.2 years

Summary

At present, the technology of anaerobic digestion of livestock wastes is well established; the economics of the process, however, are not. Part of the reason that economics do not clearly favour the installation of farm digesters is the relatively low cost of energy (e.g. natural gas or propane) in parts of Ontario and other regions of Canada. When energy prices are low, protein recovery from the digester effluent is generally required to make the system economically feasible. Systems can be economically feasible for energy (biogas) production alone where energy prices are higher.

With relatively low energy prices, one of the major difficulties in planning farm digesters is matching farm energy requirements with digester biogas energy production. For this reason, farms must be evaluated individually so that biogas production can be used in the most cost-effective manner.

Anaerobic digestion is currently attractive as a means of energy production, SCP production, and pollution and odour reduction. For smaller farms, the technology is not now as attractive financially due to economies-of-scale. Rising energy prices and advanced systems designs may shortly enable smaller farms to invest in this technology with a favourable payback period.

References

1 Buswell, A. M., "Important Considerations in Sludge Digestion. Part III. – Microbiology and Theory of Anaerobic Digestion", **Sewage Works Journal**, 19 (1): 28-38, 1947.

2 CANVIRO Consultants Ltd., "Thermophilic Anaerobic Fermentation of Beef Cattle Manure for Protein and Methane Production, Final Report on 1979/80 Laboratory Studies", **Report submitted to National Research Council of Canada**, Saskatoon, Saskatchewan, 1980.

3 CANVIRO Consultants Ltd., **Internal Report on Economics of Farm-Scale Digesters**, 1982a.

4 CANVIRO Consultants Ltd., "Final Report on 1981/82 Laboratory Studies of Anaerobic Fermentation of Beef and Swine Manure for Protein and Methane Production", **Report submitted to National Research Council of Canada**, Saskatoon, Saskatchewan, 1982b.

5 CANVIRO Consultants Ltd., "First Progress Report on Evaluation and Optimization of Protein Recovery from Anaerobically Digested Beef Cattle Feedlot Waste", **Report submitted to Agriculture Canada**, Ottawa, 1982c.

6 MacGarry, B., "Biogas for Water Pumping in Botswana", **Paper presented at Workshop on Low Cost Energy for Water Pumping**, held at Botswana, November 24-9, 1980.

7 Pyle, D. L., "Biogas Technologies: A Discussion Paper", **presented at Workshop on Low Cost Energy for Water Pumping**, held at Botswana, November 24-9, 1980.

8 Schlenz, H. E., "Important Considerations in Sludge Digestion. Part I. – Practical Aspects", **Sewage Works Journal**, 19 (1): 19-27, 1947.

9 Sharma, Y. N., "Bio-gas Development and Application in India". **Paper presented at Workshop on Low Cost Energy for Water Pumping**, held at Botswana, November 24-9, 1980

Notes